eRD6 Progress Report

Kondo Gnanvo

On Behalf of eRD6

EIC GENERIC DETECTOR R&D ADVISORY COMMITTEE MEETING

January 18, 2017

The eRD6 Consortium

- **Brookhaven National Laboratory (BNL)**
  - People: E.C Aschenauer, B. Azmoun, A. Kiselev, M. L. Purschke, C. Woody
  - R&D: Mini-Drift detector; TPC/Cherenkov prototype (TPC-C); zigzag pad development.
- **Florida Institute Of Technology (FIT)**
  - People: M. Bomberger, M. Hohlmann
  - R&D: Large & low mass GEM with zig-zag readout structures.
- **INFN Trieste**
  - People: S. Dalla Torre, S. Dasgupta, G. Hamar, S. Levorato, F. Tessarotto
  - R&D: Hybrid MPGD for RICH applications.
- **Stony Brook University (SBU)**
  - People: K. Dehmelt, A. Deshpande, N. Feege, T. Hemmick
  - R&D: Short radiator length RICH; Large mirror coating, TPC-IBF
- **University Of Virginia (UVa)**
  - People: K. Gnanvo, S. Jian, N. Liyanage, J. Matter
  - R&D: Large & low mass GEM with u-v readout; Chromium-GEM (Cr-GEM).
- **Yale University**
  - People: D. Majka, N. Smirnov
  - R&D: 3-D-coordinate GEM readout; hybrid gain structure.

UNIVERSITY of VIRGINIA

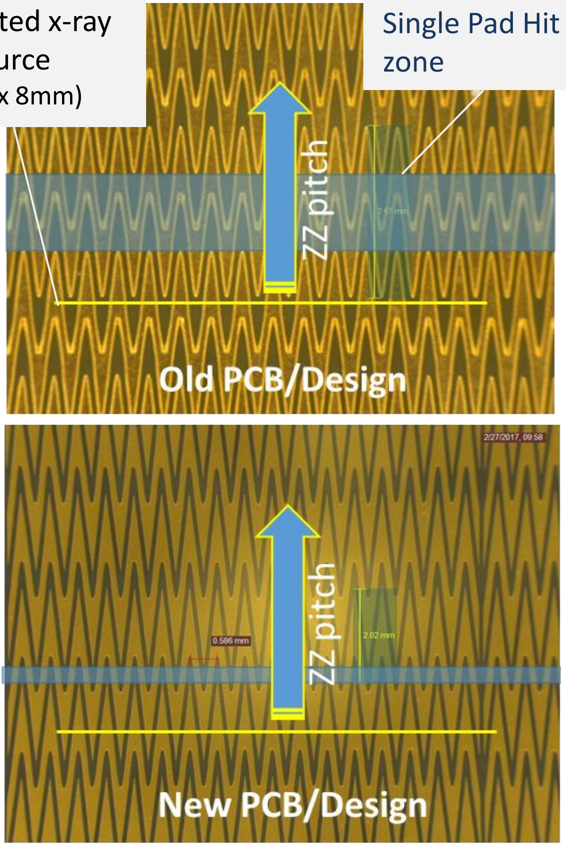
Progress @ Brookhaven National Lab

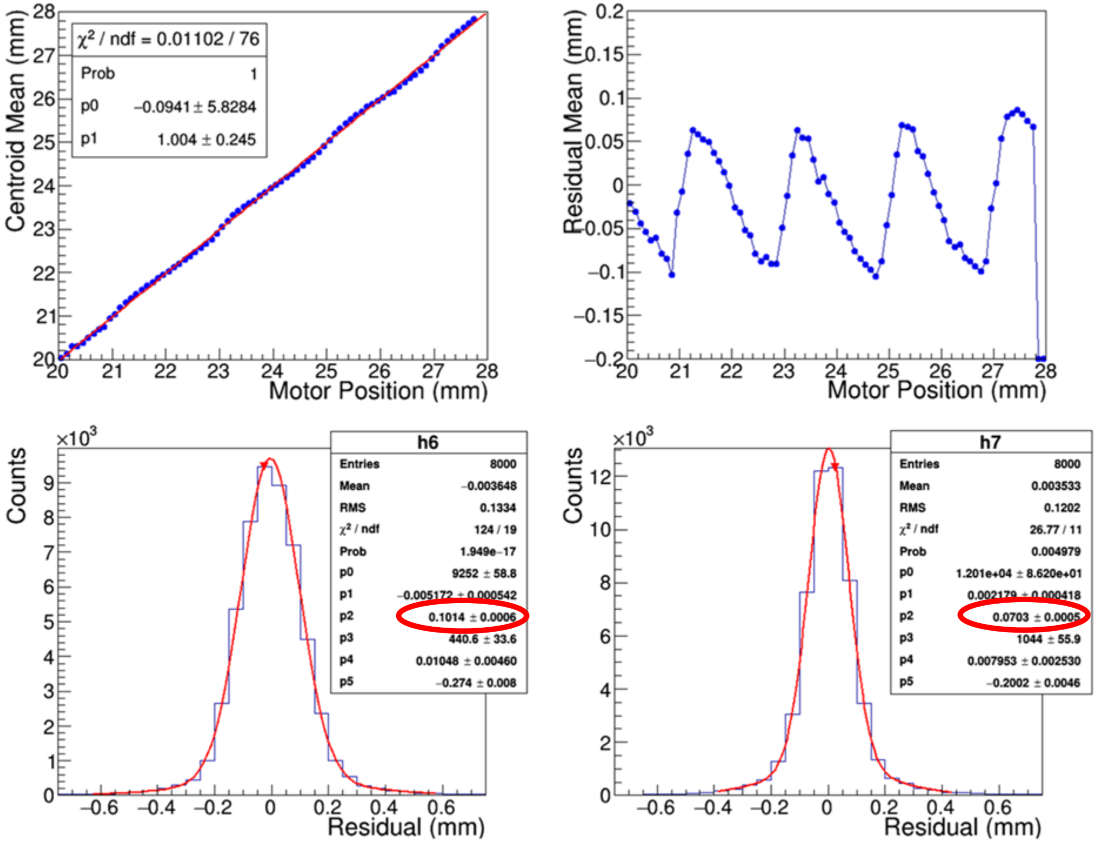
Progress @ BNL: Optimizing Zigzag patterned 4-GEM Readout

In-lab X-ray scans across zigzag readout

Collimated x-ray Line Source (~50µm x 8mm)

Single Pad Hit zone





- Zigzag pads offer a low segmentation, but high performance option for a TPC readout
- The centroid – motor position correlation plot for the latest iteration of the zigzag readout is monotonically continuous when the measurement is performed at standard values of gain (unlike earlier reported measurements).
- However there is still a notable differential non-linearity present in the data.
- The position resolution using the collimated beam of x-rays was measured to be 101µm and 70µm without and with the DNL unfolded from the data, respectively, compared to 134µm and 98µm respectively for the older PCB.
- The rate of single-pad hits also dropped from ~30% to ~3% of all recorded events.

Measured physical ZZ Parameters	Pitch (mm)	Period (mm)	Trace (mm)	Gap (mm)	Interleaving/ Pitch (%)	Gap / Pitch (%)	Electrode Area / Tot. PCB Active Area (%)
Old Design/PCB	2.00	0.5	0.159	0.082	69.0	4.1	66.0
New Design/PCB	2.00	0.586	0.141	0.084	82.5	4.2	63.0

➢ Biggest improvements in new PCB design include increased interleaving and a reduced single pad hit zone, however the distortions from chemical etching are still present in the new PCB

Progress @ BNL: Next iteration Zigzag PCB: scan zigzag parameter space

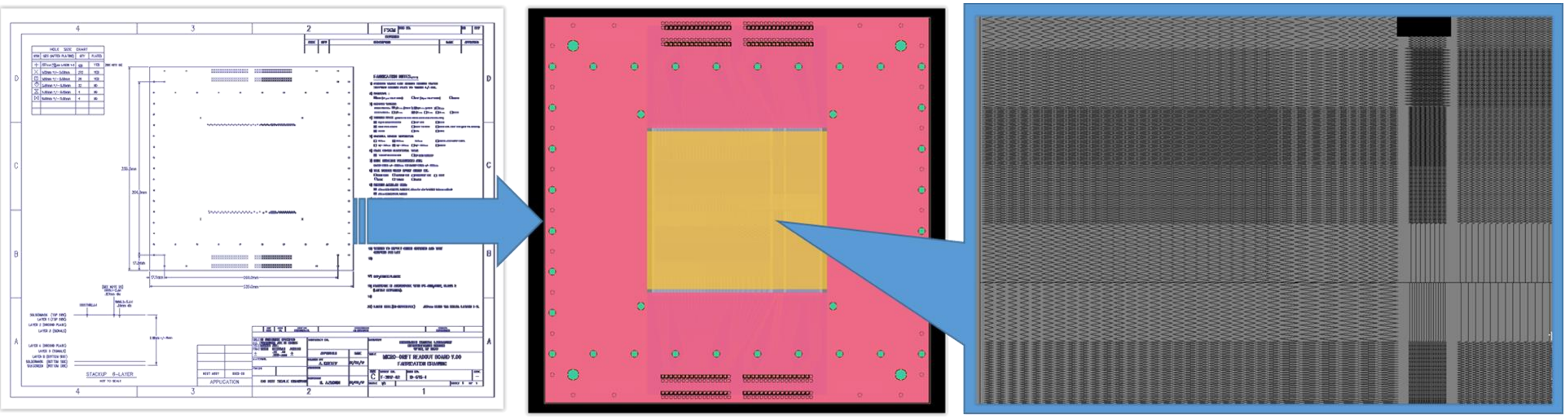
- Using a novel laser ablation process we will fabricate the next iteration zigzag PCB which will not suffer from the distortions (i.e., over-etched zigzag tips, and under-etched troughs) and limitations (e.g., 3mil gap between pads) of standard chemical etching

- Laser ablation allows for the possibility to probe the zigzag geometry parameter space down to the level of 1mil or less

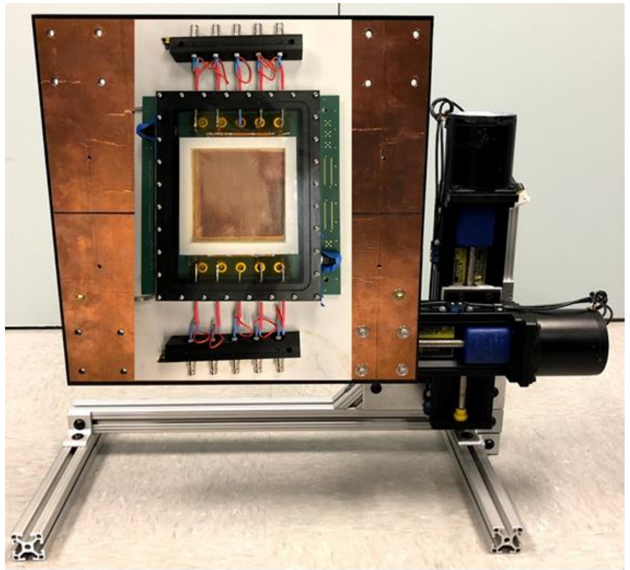
- We have already designed and submitted the drawings for fabricating a PCB comprising 128 groups of 4-5 zigzag pads, each with slightly differing zigzag geometries.

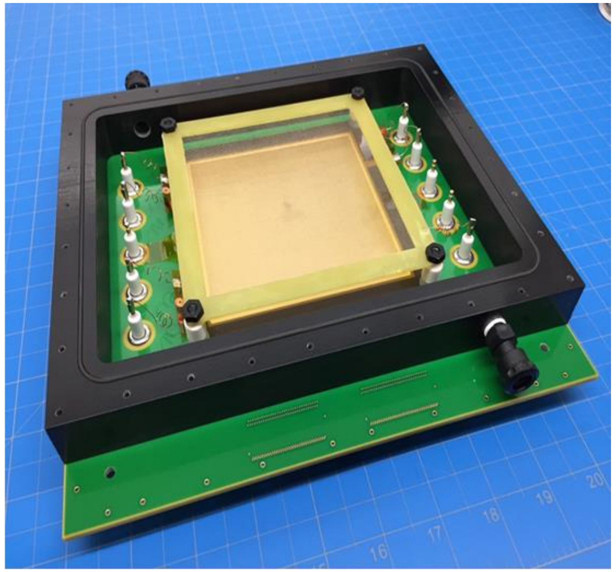
- The PCB will be installed onto a 4-GEM detector and brought to a beam test in order to scan an interesting region of the zigzag geometry parameter space.

Multi-ZZ patterned PCB drawings submitted for fabrication using laser ablation



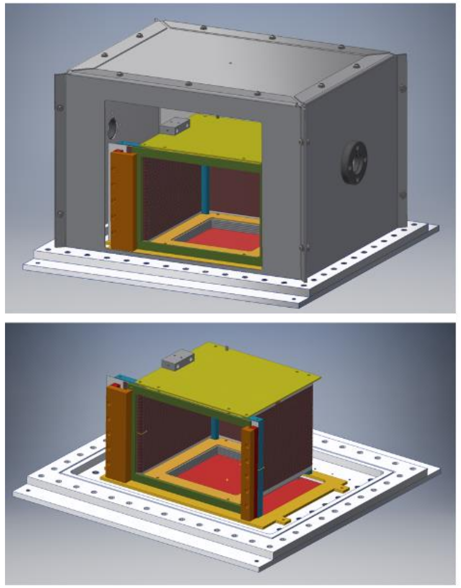
GEM detector equipped with Multi-ZZ patterned PCB mounted to XY-moveable stage for beam test measurements

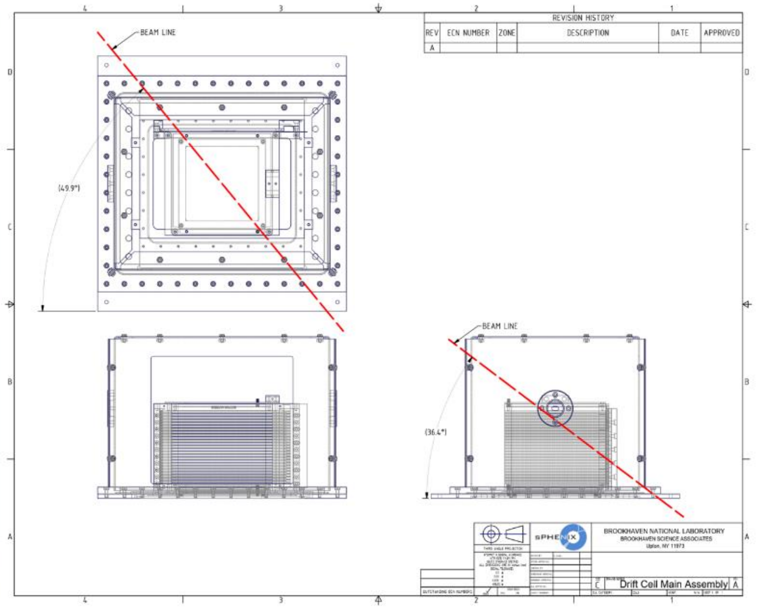




Progress @ BNL: In-lab measurements of ZZ PCB

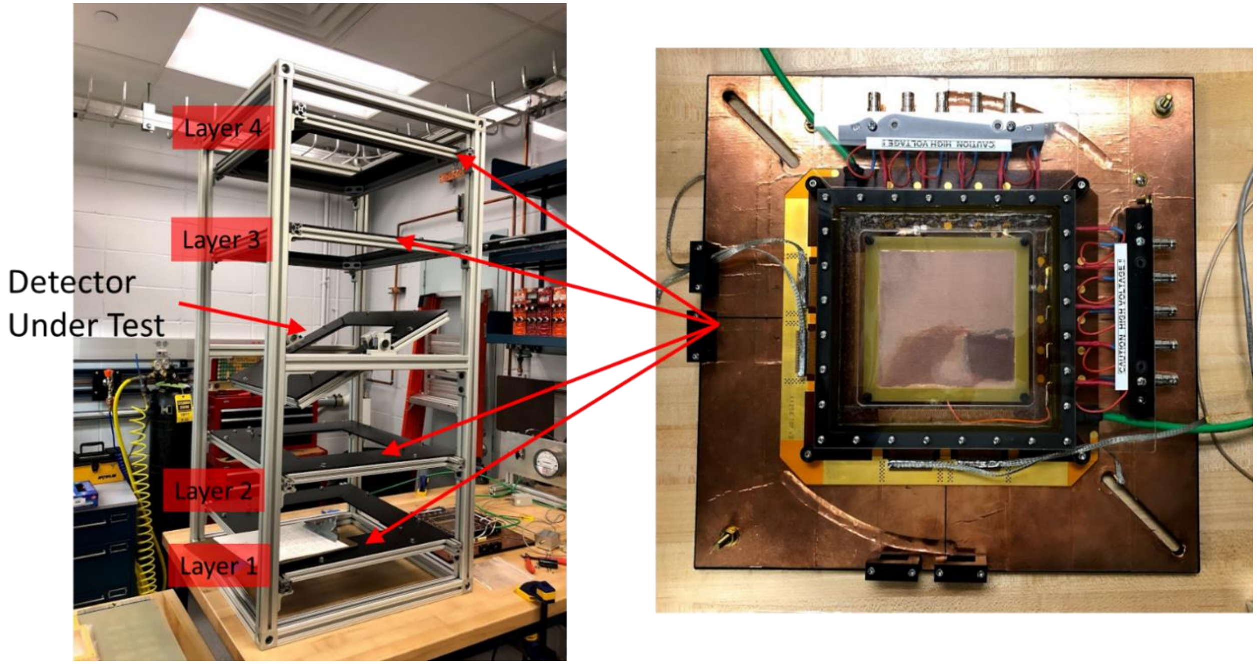
Prototype TPC





- Design completed; assembly has begun and will be completed in a few months
- 10 × 10 × 10 cm^3 field cage, coupled to 10 × 10 cm^2 GEM readout
- Zigzag PCB used for readout to reconstruct real tracks
- Can be used for TPC gas studies, including measurements of drift velocity, charge spread, energy resolution, ion back-flow, etc.
- May be brought to beam test some time this year

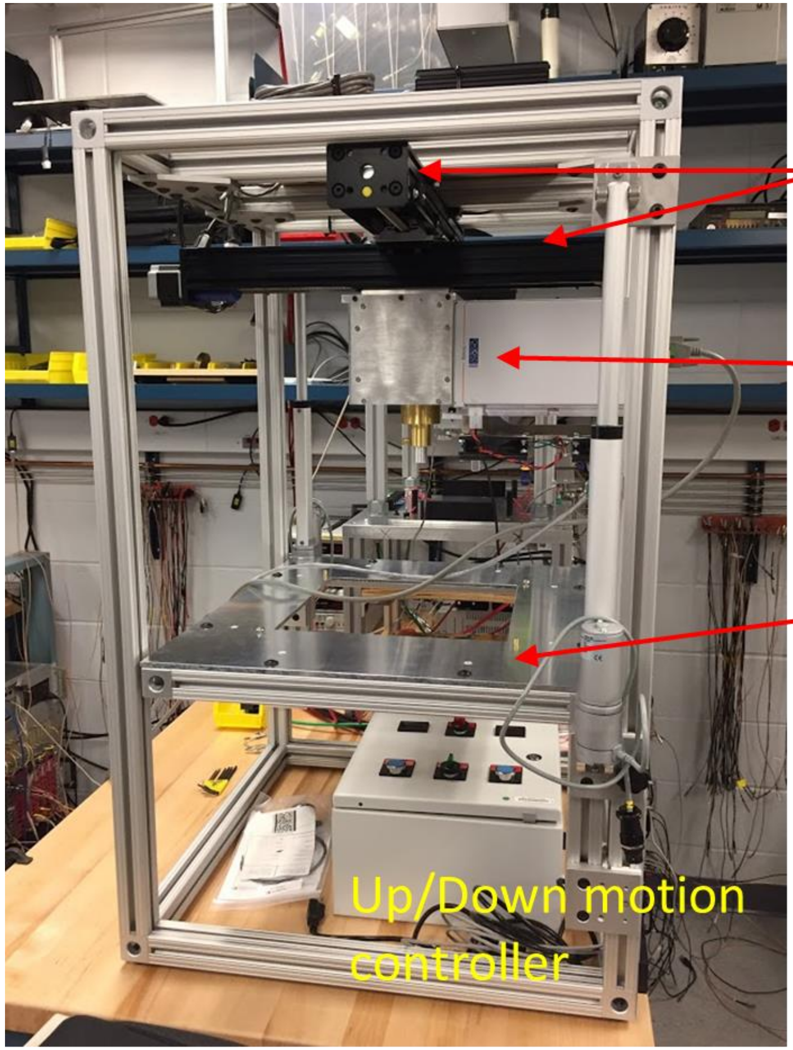
Cosmic ray telescope

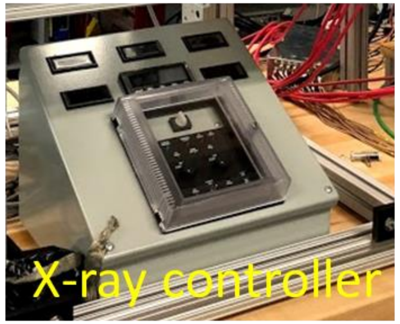


- Assembly almost complete
- 4-layer GEM-based telescope with COMPASS X-Y readout
- Expect at least 60μm space point resolution per layer in 2D
- Will allow for in-lab resolution measurements using real tracks for detector under test
- Plan to study prototype TPC and get realistic measures of resolution for ZZ PCB's to compliment results from x-ray scans
- Will also be used as reference tracker for beam test in July 2018

Progress @ BNL: New high intensity X-ray scanner

- X-ray scanner assembly is complete
- The scanner consists of a 40W x-ray source with a 38^o cone of illumination, a big improvement over the older 3W source with a 120^o cone. (We estimated the scan time of a zigzag PCB to be about 1-2hrs. for the new scanner, compared to about 24hrs. for the older setup.)
- The new stage is also considerably larger with a travel of 15” in both the X and Y directions, compared to about 6” for the older setup.
- We manufactured new collimators for the new setup which have significantly smaller slit lengths for the purpose of probing finer structures of readout electrodes under study (albeit at the cost of losing some rate).
- The X-ray shielding/collimator box passed the BNL radiological control requirements and is considered a level-1 radiation generating device for use in the lab.
- After initial tests, the output from the collimator was significantly less than expected, due to the presence of materials in the exit window of the x-ray source with large mass attenuation coefficients.
- This was not readily disclosed by the manufacturer prior to purchasing the device. However, we are currently investigating options to recover the lost rate, including employing a doubly curved diffractive crystal optic which has a significantly larger numerical aperture than a simple collimator and has the ability to focus the collected light onto a very small spot size.





Progress @ BNL: Plans & Milestones

Plans

- **Zigzag Pad development:** we will continue to develop and further optimize the zigzag patterned readout by pursuing a laser ablation process for the accurate reproduction of our zigzag designs and will continue to make our simulations more realistic.
- **Beam test with multi-zigzag PCB:** we plan to carry out a beam test of a new zigzag PCB consisting of many regions with slightly different zigzag shaped pads for the purpose of scanning the parameter space of the zigzag geometry.
- **Measurements with GEM-based cosmic ray telescope:** we plan to make measurement of the position resolution of new zigzag PCB's in the lab using a high resolution, GEM-based cosmic ray telescope.
- **GEM Studies using TPC gas mixtures in a compact TPC prototype:** we plan to use a compact TPC prototype detector to reconstruct particle tracks with newly developed zigzag PCB's in the lab and plan to study various candidate TPC gases in the same setup.

2018 Milestones:

- Early January: Production of multi-zigzag PCB using laser ablation process
- Mid. January – Mid. February: In-lab partial x-ray scan of multi-zigzag PCB
- End of February – End of March: FNAL beam test to study zigzag geometries contained in multi-zigzag PCB
- April – July: Analysis of beam test data and studies with compact TPC prototype
- Early July: 2nd beam test with next iteration zigzag PCB + compact TPC (tentative)

Progress @ Florida Tech

Progress @ Florida Tech: FIT Prototype Module Features

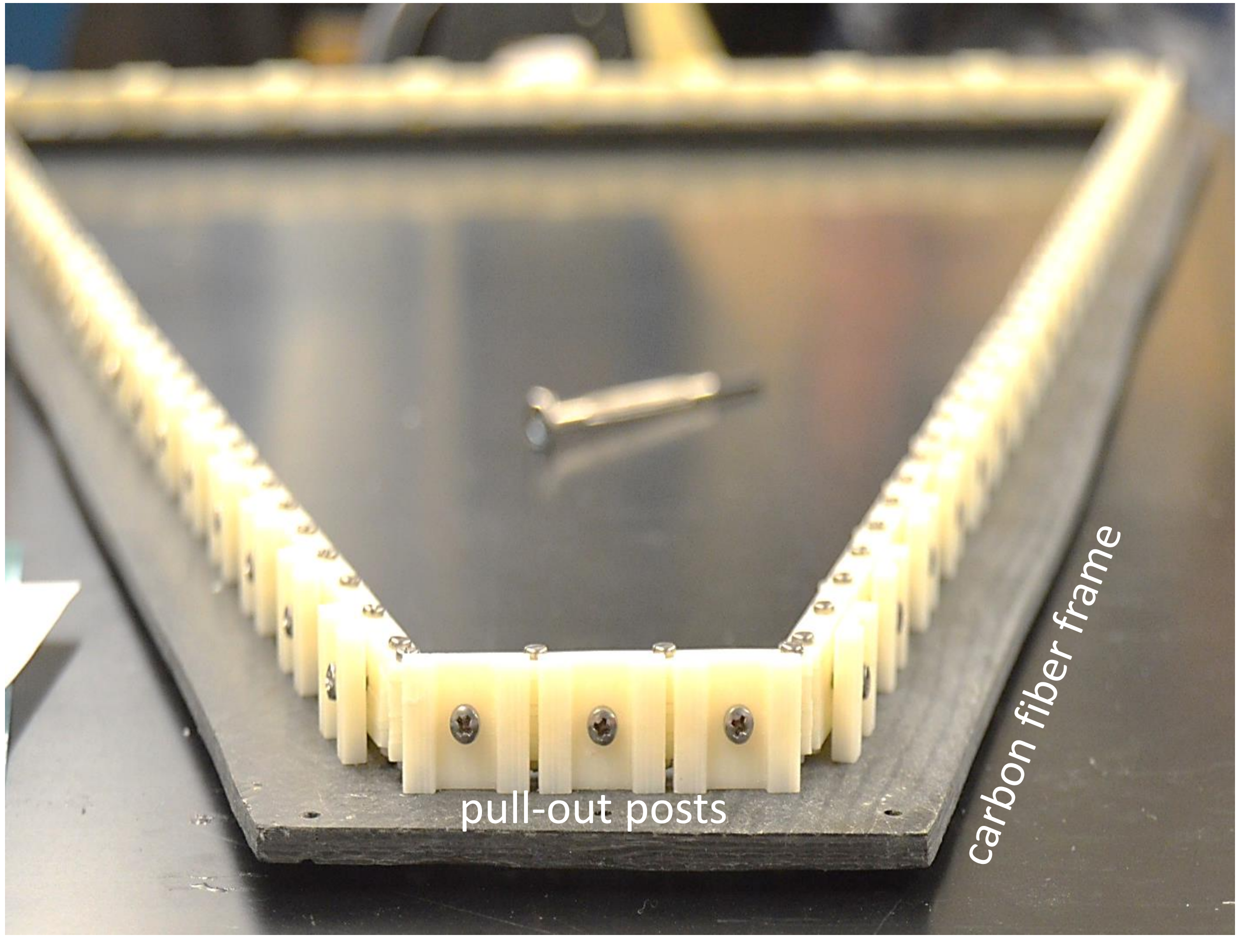
Forward Tracker Prototype:

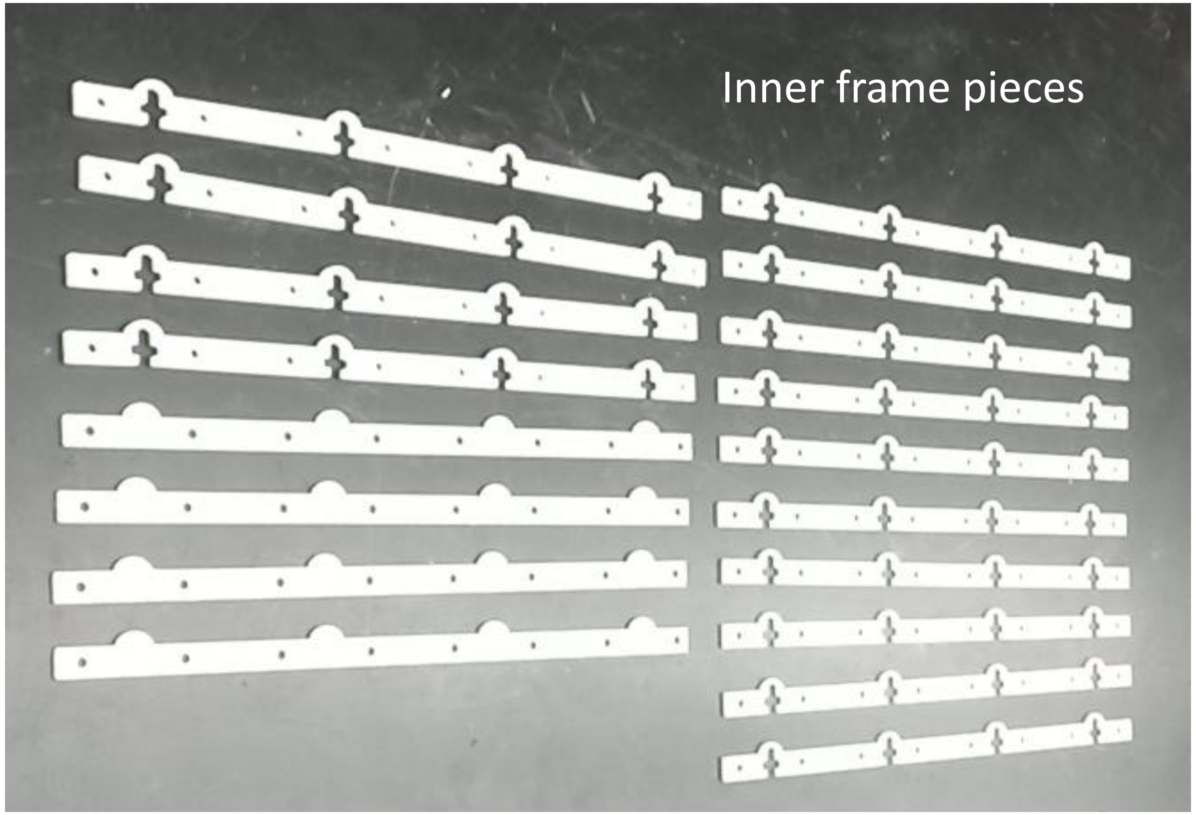
- Large trapezoidal Triple-GEM Detector (3/1/2/1 mm gaps)
- Mechanical detector assembly **without any spacers in active area**
- **Construction without rigid PCBs (drift, readout)** to reduce mass, rad. length
  - Signal readout strips on a foil
  - GEM foil as drift electrode
  - 3 GEM foils for gas gain
  - Stiff carbon fiber frames on perimeter to hold foil stack tension
- **Zigzag strip readout** to minimize number of strips & electronic channels
  - reduce system cost
  - maintain good spatial resolution
  - all electronics placed on wide end of trapezoid

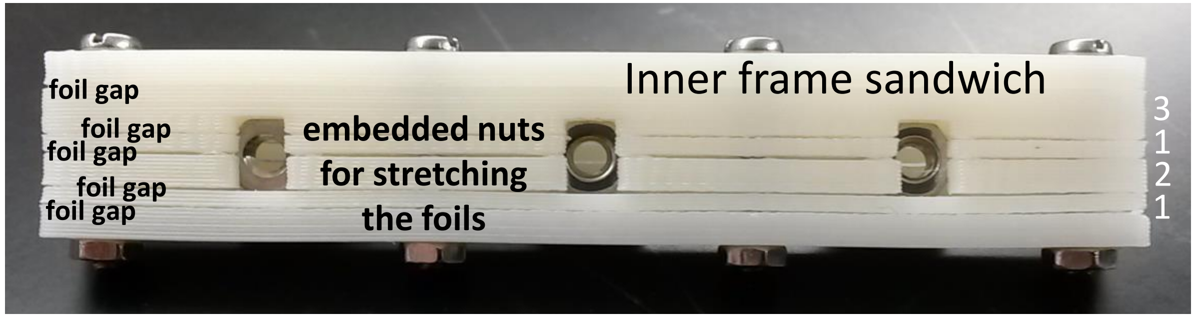
Progress @ Florida Tech: FIT Prototype Test Assembly

Use low-mass, low-cost 3D-printed ABS material:

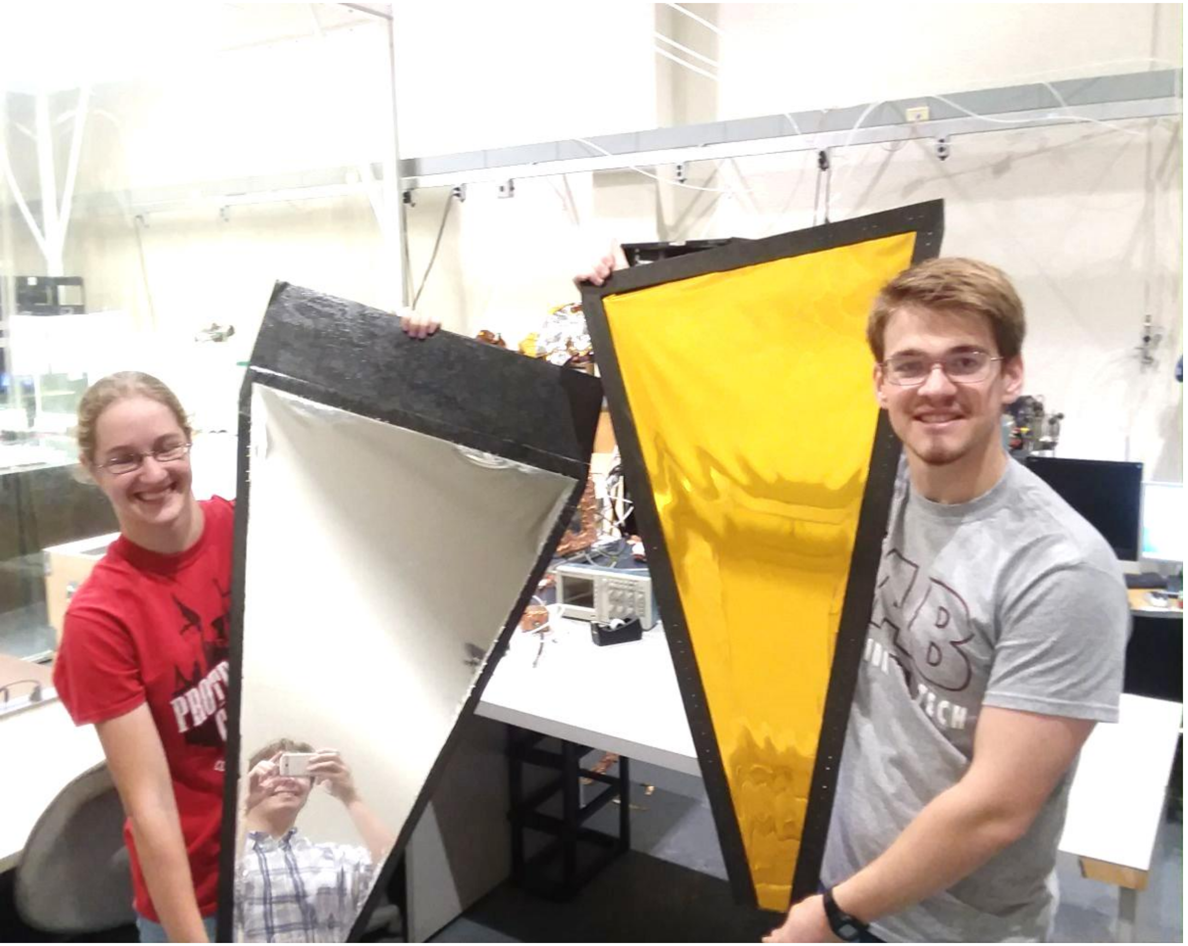
- Inner frames for sandwiching 5-foil stack
- Pull-out posts to stretch foil stack against







Progress @ Florida Tech: Gas Windows & Outer Frame



- Aluminized Kapton foils glued onto carbon fiber frames serve a gas windows
- Work done by EIC research undergraduates Sam and Matt

- Fiberglass material machined at CERN
- Viton O-rings will seal against carbon fiber frames

Progress @ Florida Tech: FT Prototype Material Accounting

Active Area:

Detector with PCBs (e.g. CMS)	Thickness (mm)	% of Rad. Length
2 PCBs (drift and readout)	**3.180**	**3.914**
3 GEMs	**0.180**	**0.261**
Polyimide	0.150	0.051
Copper	0.030	0.210
Total		**4.175%**

Detector with foils only (EIC)	Thickness (mm)	% of Rad. Length
2 Al-Polyimide foils (gas seal)	**0.051**	**0.0184**
Polyimide	0.051	0.018
Al	0.0002	0.0004
3 GEMs	**0.180**	**0.261**
Polyimide	0.150	0.051
Copper	0.030	0.210
1 GEM as drift foil	**0.060**	**0.087**
Polyimide	0.050	0.017
Copper	0.010	0.070
Readout foil	**0.080**	**0.227**
Polyimide	0.050	0.017
Copper (15 μm each side b/c of vias)	0.030	0.210
Total		**0.593%**

Factor 7.0 reduction

Progress @ Florida Tech: Plans, Milestones & Concerns

- Plans
  - Assemble detector and perform quality control (based on CMS GEM production)
  - Measure performance
    - ✓ with X-rays at Florida Tech
    - ✓ with beams at Fermilab
  - UG student to simulate impact of material budget on EIC detector performance

- Milestones
  - February 2018 - One-meter forward tracker prototype fully assembled
  - April 2018 - Quality control with X-rays completed
  - June 2018 - EIC simulation running at Florida Tech
  - July 2018 - Beam test at Fermilab

- Concerns
  - Pace slowed down significantly because post-doc left (funding ended Dec 2016)

Progress @ University of Virginia

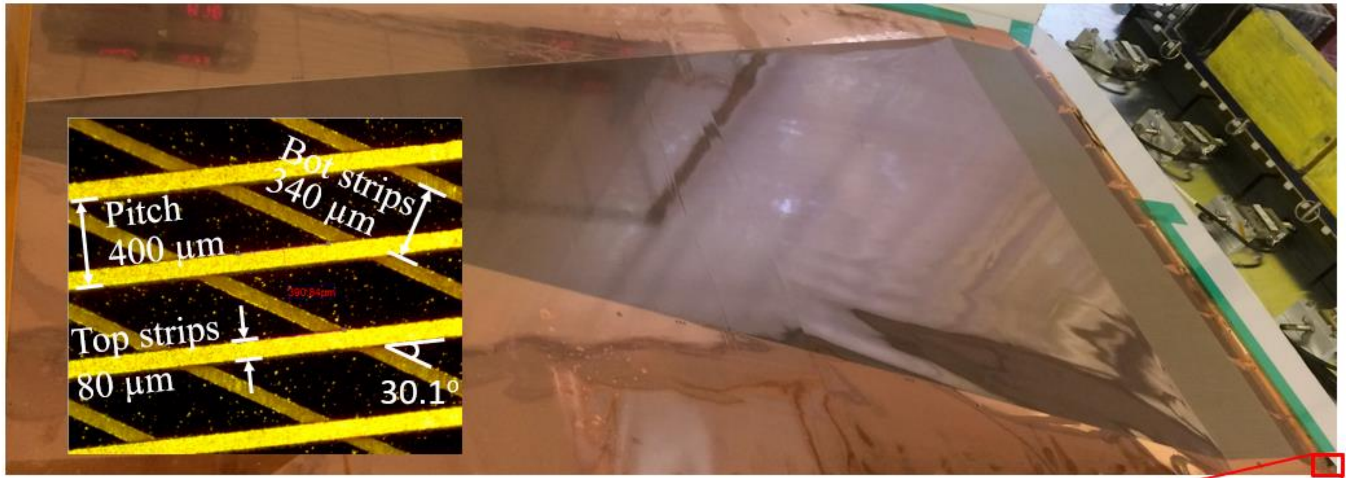
Progress @ UVa: Large FT GEM Prototype Assembly

U-V strips readout & all pieces for Zebra connection available

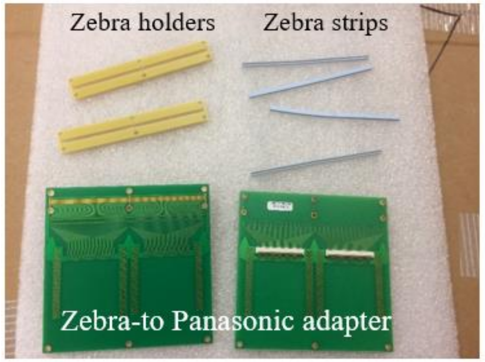
- All mechanical parts for the double sided zebra procured from CERM

⇨ 10 Zebra-to-Panasonic adapter cards &10 zebra holders

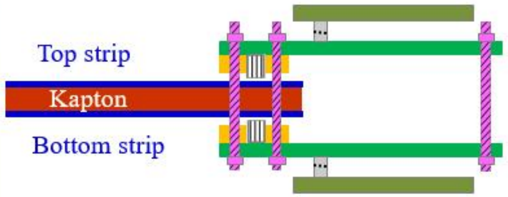
2D U-V strip flexible readout & components of double side zebra connection

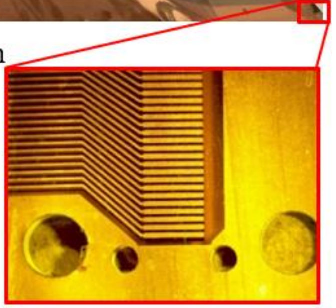


Components of zebra connection



Principle of double side zebra connection





- 2D U-V strips readout a la COMPASS, very good spatial resolution
- No metallized vias to pick up bottom strips signal ⇨Thin Cu layer
- All FE electronics read out all on the outer radius of the chamber

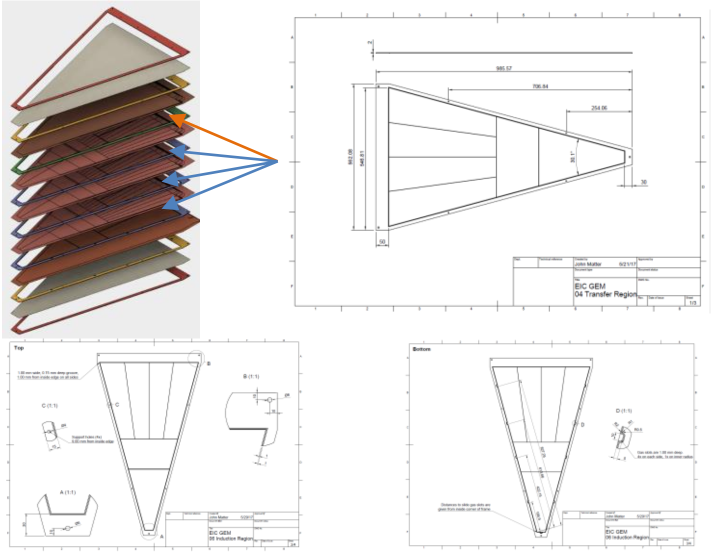
Plans for the coming months:

- Complete the design and procurement of the low cost frames
- Refurbishment of existing Clean Room tools for the assembly

Two sets of support frames

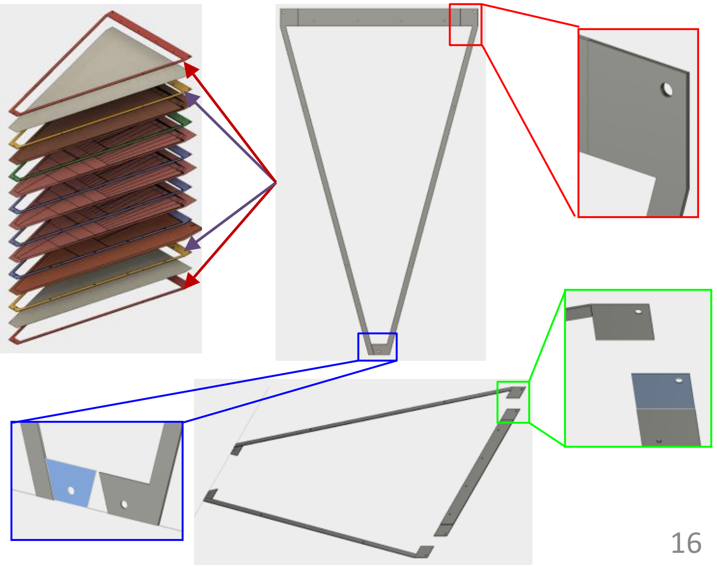
High cost Inner Frames for GEMs with spacer grids

- **Four Inner Frames** with 300 µm spacers grid for GEM foils
- Precision machining of **PERMAGLAS** by RESARM (Belgium)
- High material and machining cost



Low Cost Outer Frames without spacer grids

- **Four Outer Frames** for gas window foils without spacers grid
- Each frame made of four **G10** pieces cut out in local UVa machine shop
- Low material and production cost

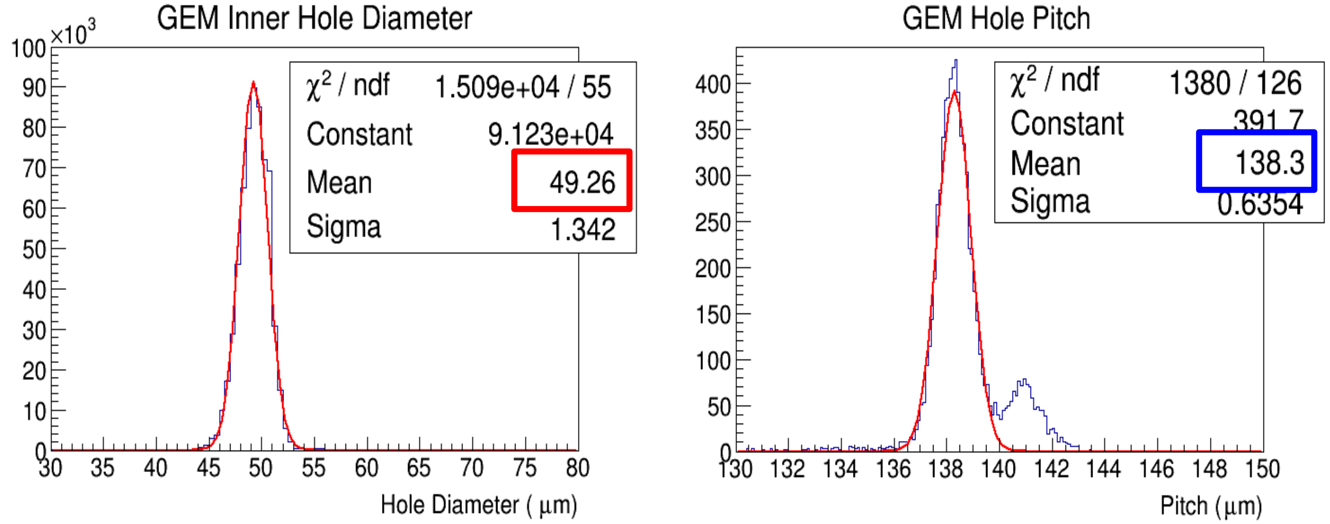


Progress @ UVa: Optical Inspection of Chromium GEMs

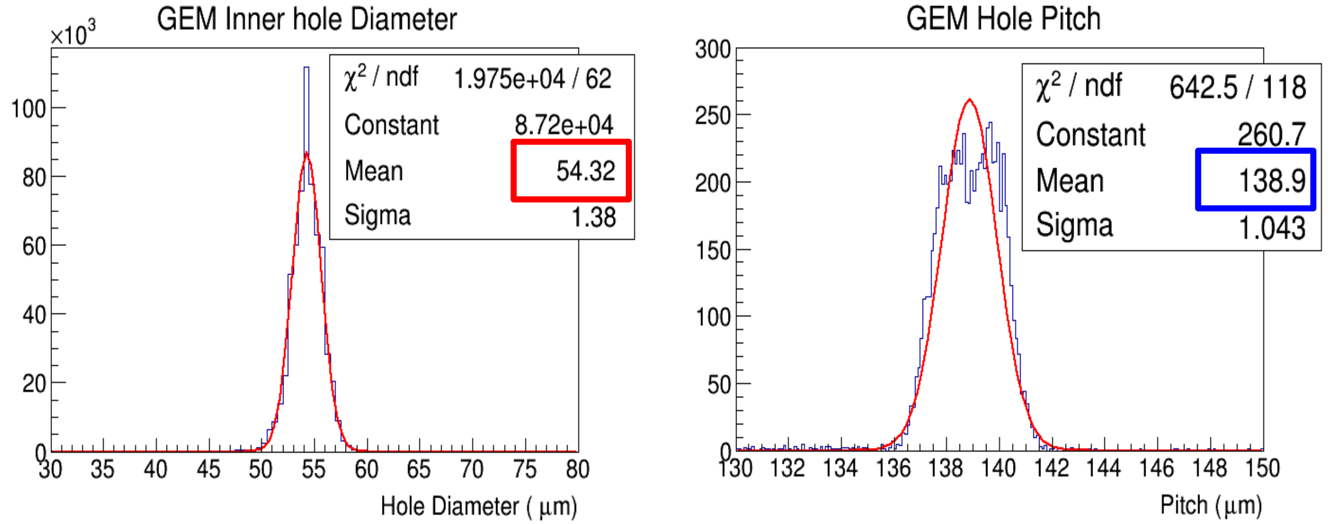
Optical inspection with GEM CDD Scanner at Temple U.

- Scan 2 Cr-GEM foils (one damaged and one good foil)
- Outer hole size turns out to be very challenging:
  - ⇨ Poor contrast from the back light transmission
  - ⇨ Poor image resolution
- Good uniformity for the inner hole diameter
- Hole pitch ~138 μm, 2nd peak at ~141 μm for both foils
  - ⇨ Second peak is more pronounced for the damaged foil

Good foil (Cr-GEM3)



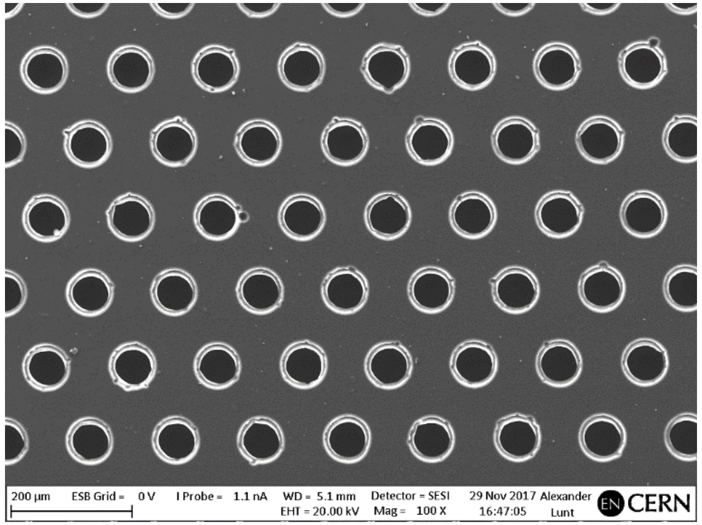
Damaged foil (Cr-GEM1)

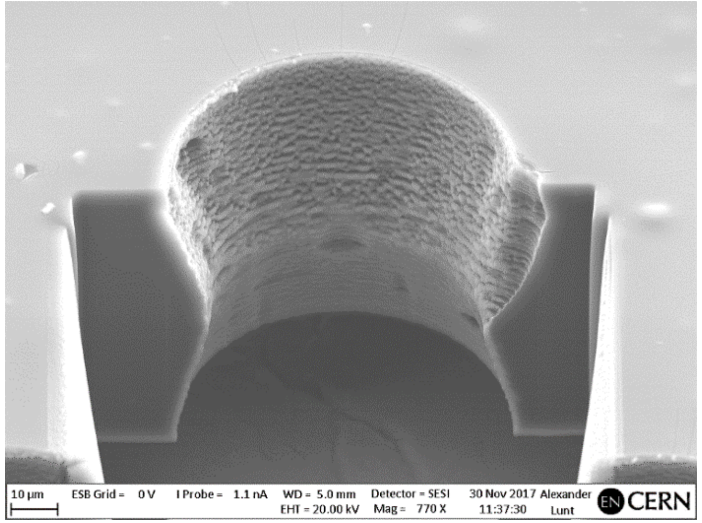


Progress @ UVa: SEM of damaged foil (Cr-GEM1)

Top side

SEM images of the top of the damaged Cr-GEM1 foil, as expected, SEM images of top side are good quality with holes dimensions configuration and the cross section view looking normal GEM foil





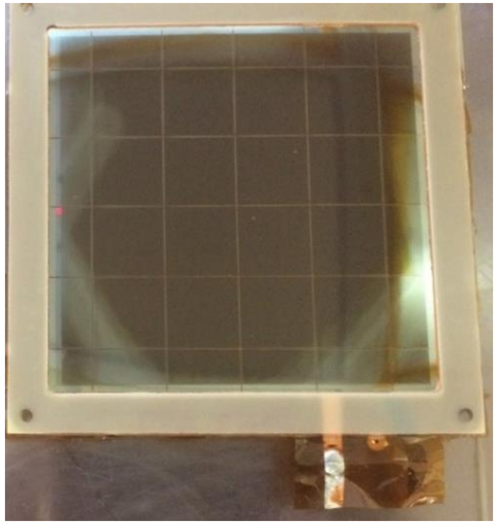
Bottom side

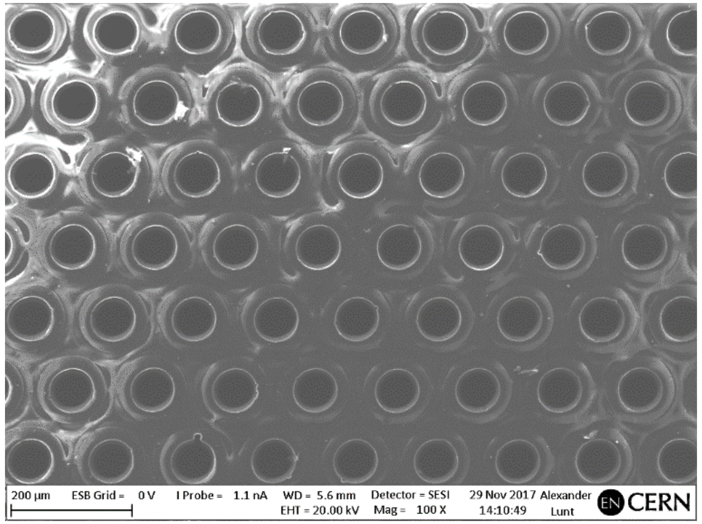
side here the Cr layer was removed appears severely distorted under SEM

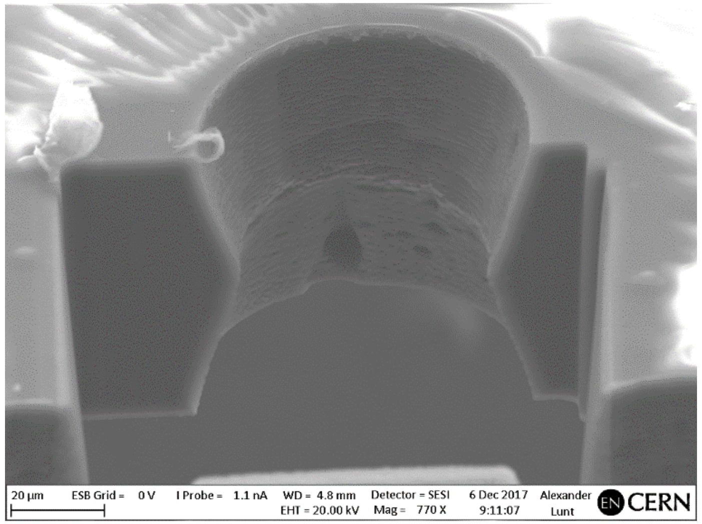
⇨ bad image resolution

⇨ Cross section of the holes:

looks as if the Cr layer melted but the Kapton looks fine



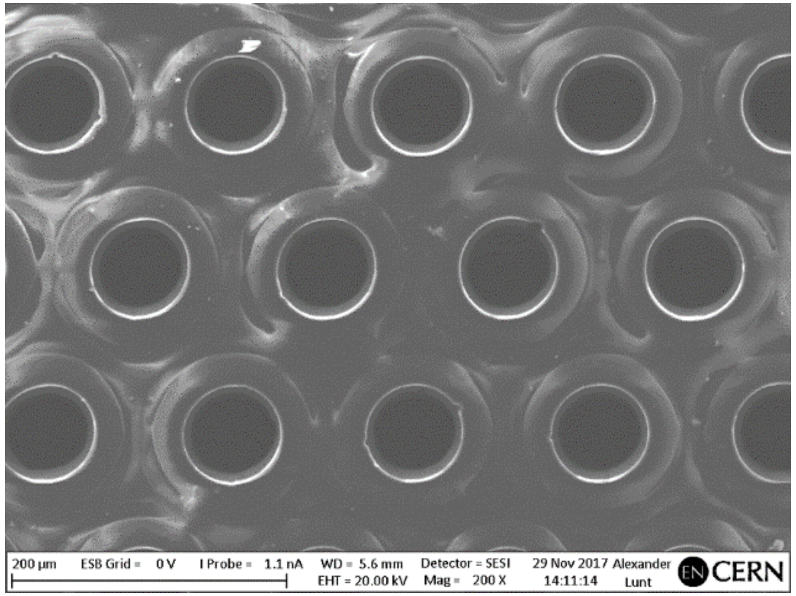




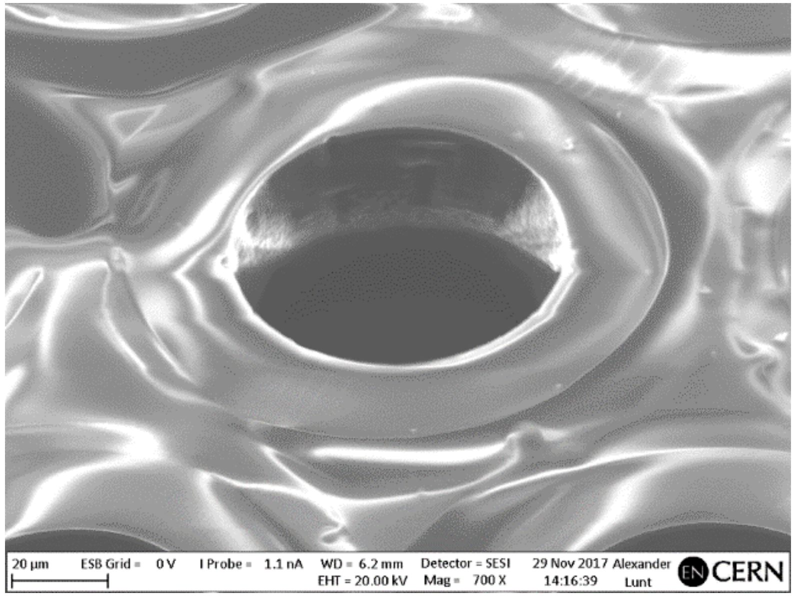
Progress @ UVa: SEM of damaged foil (Cr-GEM1)

- ❖ **Distortions are explained by the fact that the SEM measurement was performed on a non metallic surface**
- ❖ Well know issue of charging of dielectric sample when bombarded with the intense SEM beam
  - ⇨ **Problem:** Charging up disturbs the electric field around the surface under probe ⇨ poor resolution SEM image
  - ⇨ **Solution:** coating the surface with a thin conductive tape (a few nm of Au) before the SEM measurement

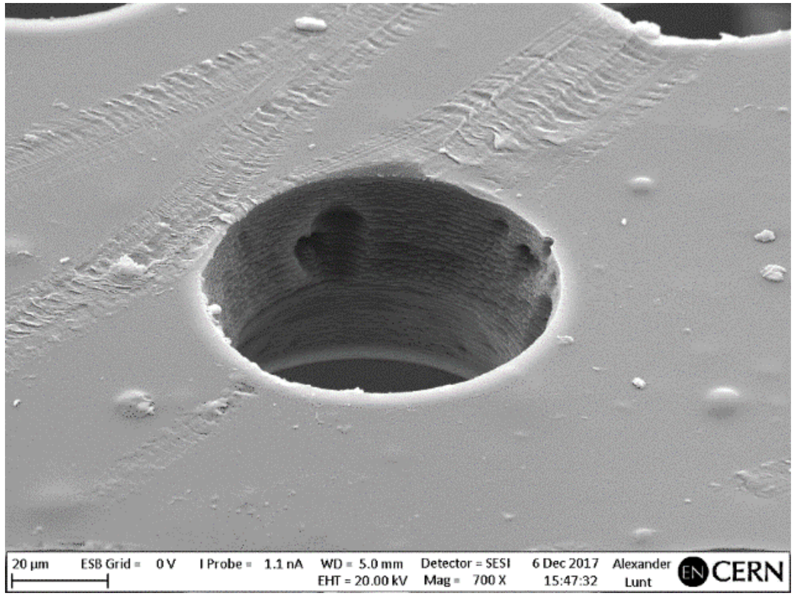
Damaged Cr-GEM1 bottom side



SEM without conductive tape



SEM with conductive tape



- ❖ Confirmation that the damages in high rate and high gain environment is limited to evaporation of the Cr layer at the the bottom side of the foil
- ❖ Discussion within the RD51 community suggest that this "evaporation" can be due to heat released during spark or plasma etching process
- ❖ No issue with the other two Cr-GEMs of the triple GEM ⇨ Hybrid Cr (top) – Cu (bottom) GEM as 3rd GEM for application that requires high rate

Progress @ UVa: Plans & Milestones

Plans

- Assemble large FT GEM prototype and characterization @ UVa Detector Lab
- Perform tests in beam at the Fermilab Test Beam Facility (FTBF) in July 2018
- Simulation of the impact of material budget on EIC detector (UVa Grad. Student)
- Start testing small 10 cm × 10 cm 2D µRWELL detector (*Order of the parts from CERN PCB workshop already processed*)
- Start the draft of the paper on Chromium GEMs for submission to NIM A or IEEE TNS

Milestones

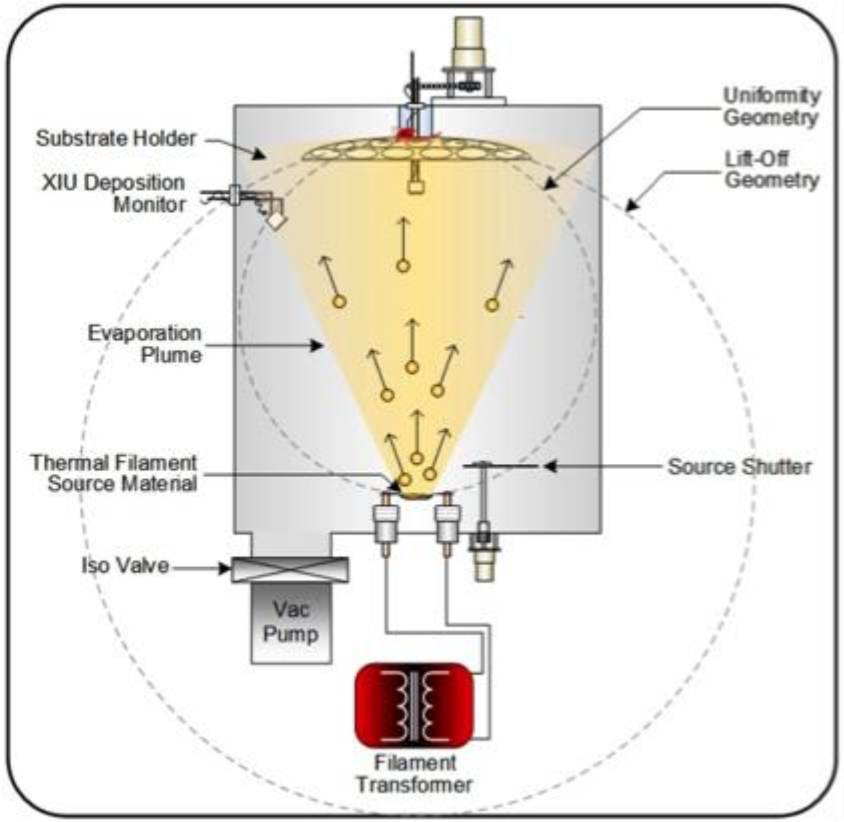
- March - April 2018: Assembly of EIC-FT GEM prototype
- Mai 2018 – June 2018: Characterization & performance tests @ UVa with Cosmic, X-rays, Sr^{90}
- June 2018: EIC simulation running @ UVa
- July 2018: Beam tests at Fermilab, Chromium GEM manuscript ready for submission

Progress @ Stony Brook University

Progress @ SBU: Installation of e-/ion-beam evaporator

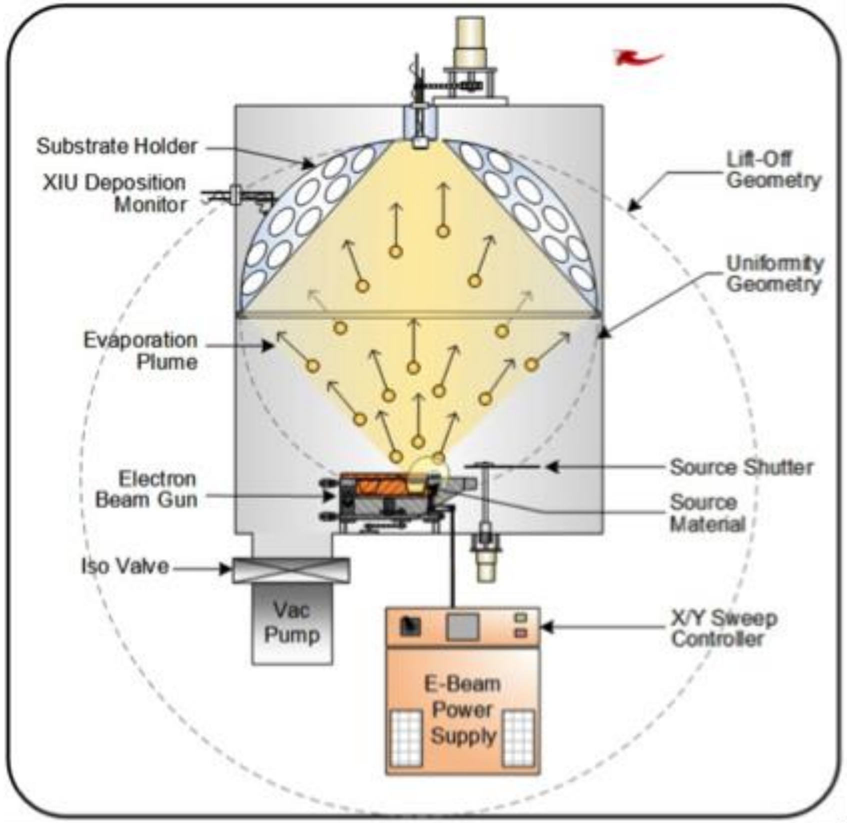
Replace this PVD configuration

- thermal evaporation unit
- Process would heat the whole crucible
  - ⇨ Contamination



with this PVD configuration

- E-Beam evaporation unit
- Satisfy the need for large size mirror coating
- Minimize contamination and damages to the substrate



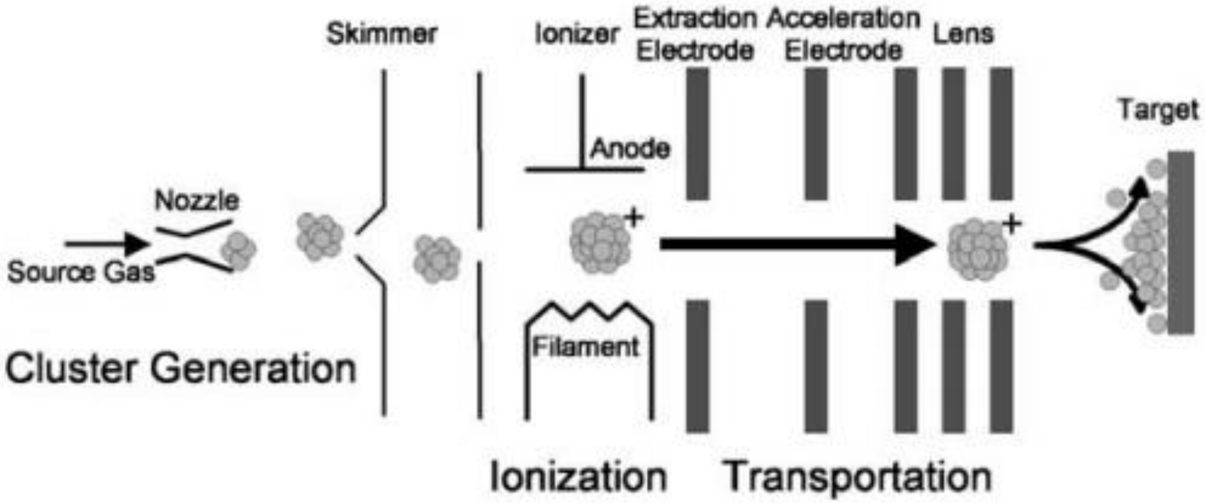
Multi crucible system

- Rotate substrate into the E-Beam

Progress @ SBU: Installation of e-/ion-beam evaporator

Ion beam setup

- Need Ion-Beam to smooth the surface during the coating.
- With enough kinetic energy, accelerated Ar-ions are capable to seal cracks and smoothen the surface ⇨**This is a crucial property of a mirror.**



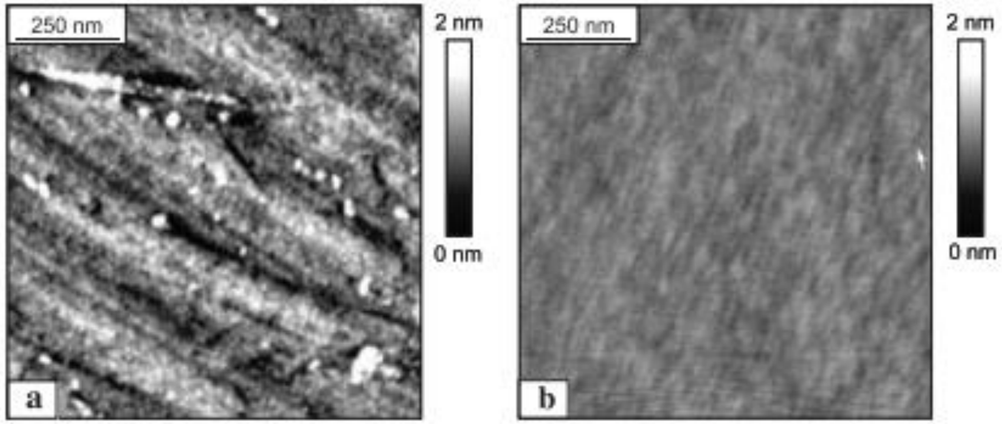


FIGURE 2 Ion beam direct smoothing of quartz surfaces. **a** Conventionally polished surface (as received), **b** after Ar^{+}-ion-beam direct smoothing (sample rotation, ion energy 800 eV, ion current density 400 μA cm^{-2}, ion incidence angle 20°, sputter time 20 min)

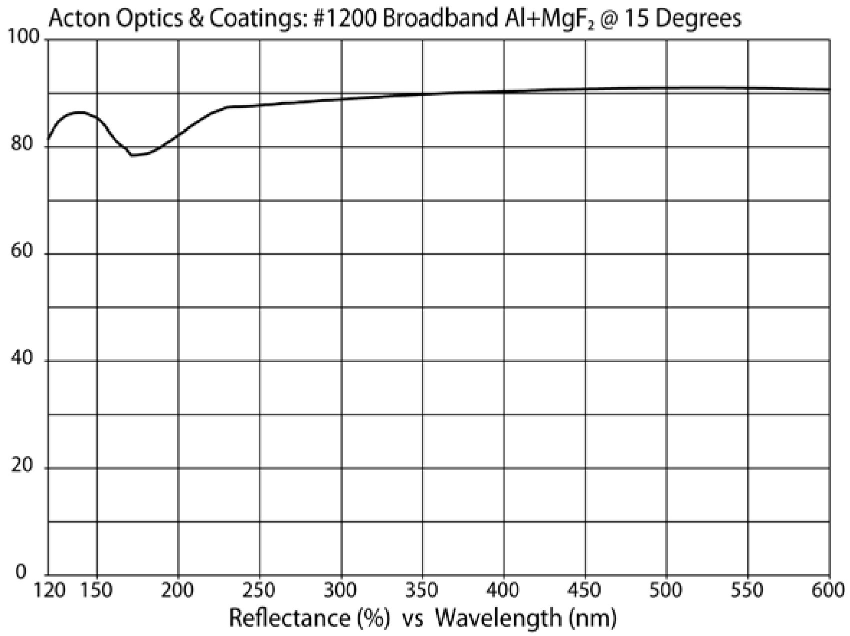
Appl. Phys. A 78, 651–654 (2004)

Progress @ SBU: Installation of e-/ion-beam evaporator

Aim: produce large size mirror coating à la LHCb RICH in house

with properties

- Large mirrors with sizes about one meter per side.
- Critical properties shown in the graph
- Coating the Al-layer of a mirror with thin layer of Magnesium Fluoride (MgF2) allows the mirror to act as a di-electric device
- **Increases the reflectivity of the mirror down to smallest wave-lengths where the largest yield of Cherenkov photons occur.**



Status: ongoing, anticipated installation and start-up in March '18

Progress @ INFN Trieste

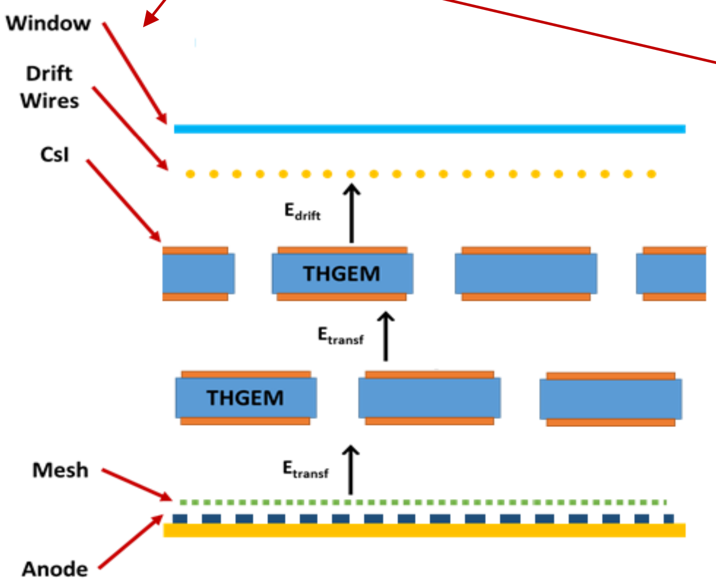
Progress @ INFN Trieste: Reminder of the R&D program

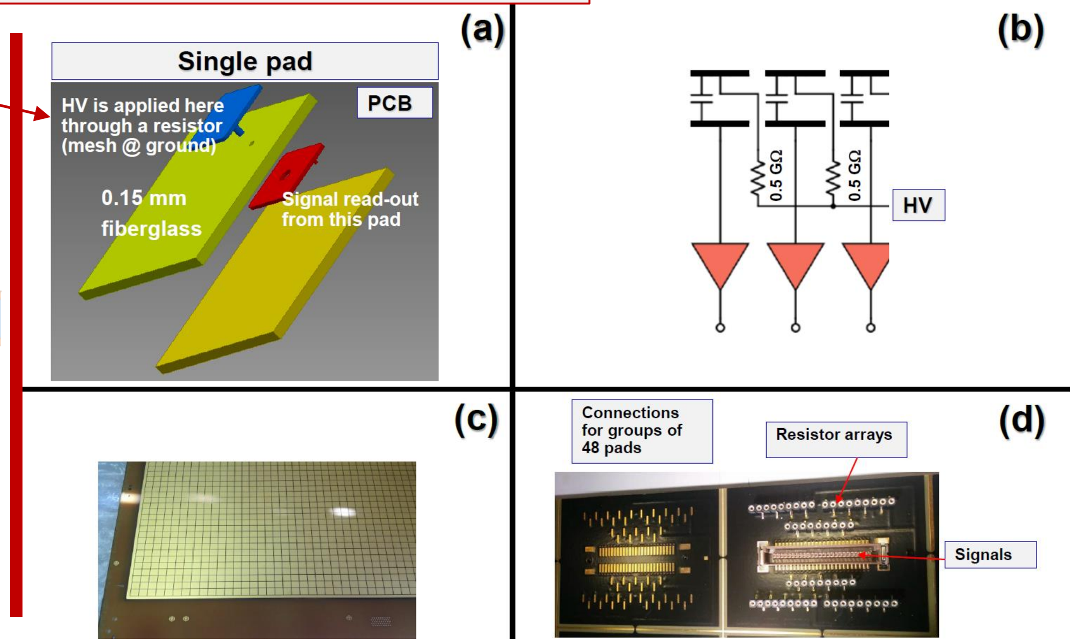
TASK: "Further development of hybrid MPGDs for single photon detection synergistic to TPC read-out sensors"

- **GOAL:**

  further improvements of the hybrid MPGD (= 2 (TH)GEMs + 1 MICROMEGAS, 3 stages in total) MPGD for single photon detection for
  - **PID, in particular high momentum RICHes**
  - **Synergies with TPC sensors by MPGD technologies**

The starting status (COMPASS RICH upgrade):
- *Scheme of the detector architecture*
- *The resistive anode by discrete elements*



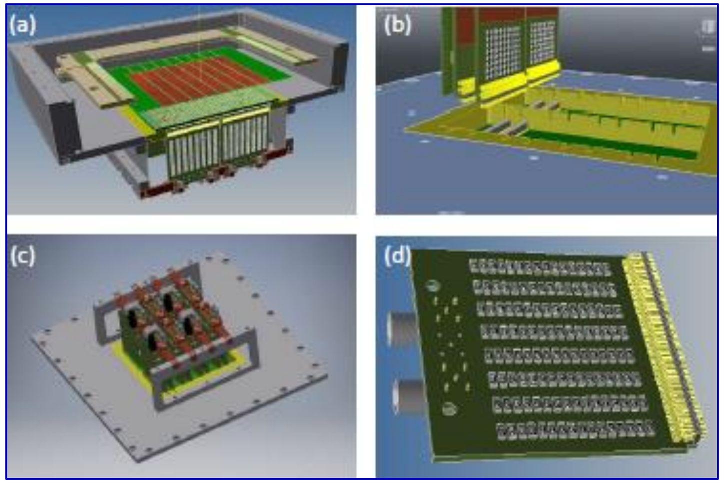


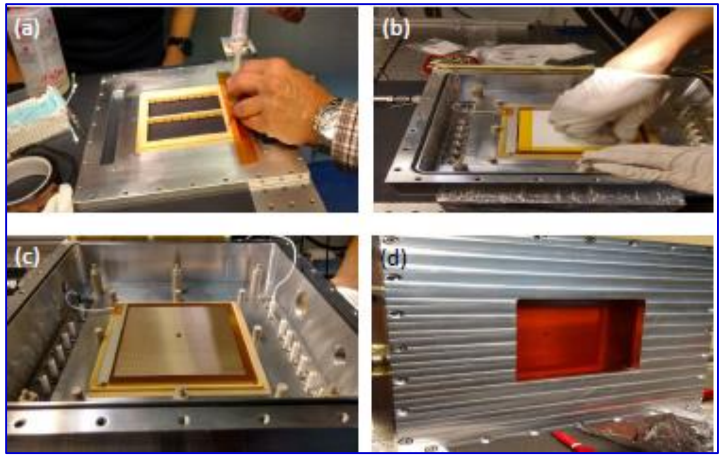
Progress @ INFN Trieste: Last 6 months

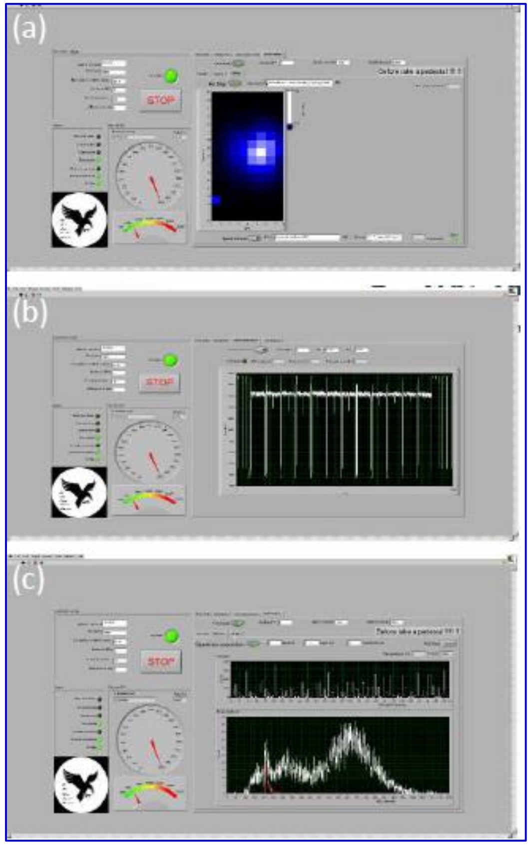
3 tasks on-going :

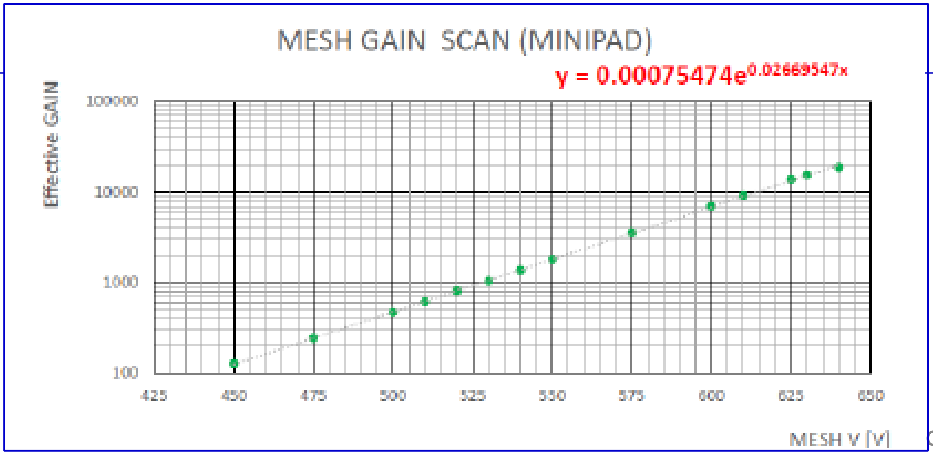
1. **Development of resistive MICROMEGAS prototype with miniaturized pad-size**
   - ✓ Design & construction completed
   - ✓ Pad size: 3 x 3 mm^2, pitch 3.5 mm
   - ✓ Modularity for extendibility: for each group of 128 pads, read-out & services make use of an area as large as the pad group itself

- Read-out via SRS by the original DAQ system Raven
  - ✓ LabView based, developed for larger band width (up to the saturation rate of the Gigabit Ethernet with the UDP protocol and with Jumbo Frame format)
  - ✓ it takes care of APV25 setting (FE chips), data collection and visualization, including pedestal subtraction & zero suppression
  - ✓ user friendly graphical interface
- Preliminary tests of the prototype (MICROMEGAS stable up to a gain of 20k!)







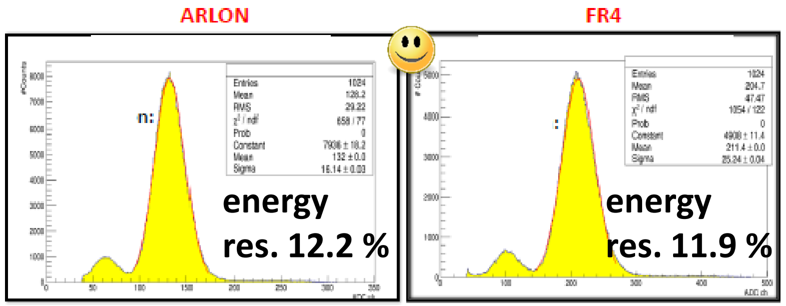


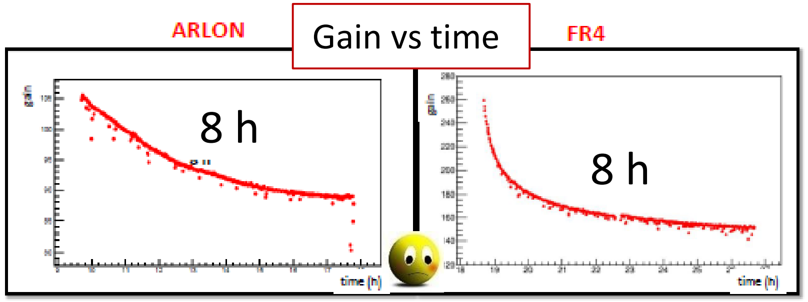
Progress @ INFN Trieste: Last 6 months

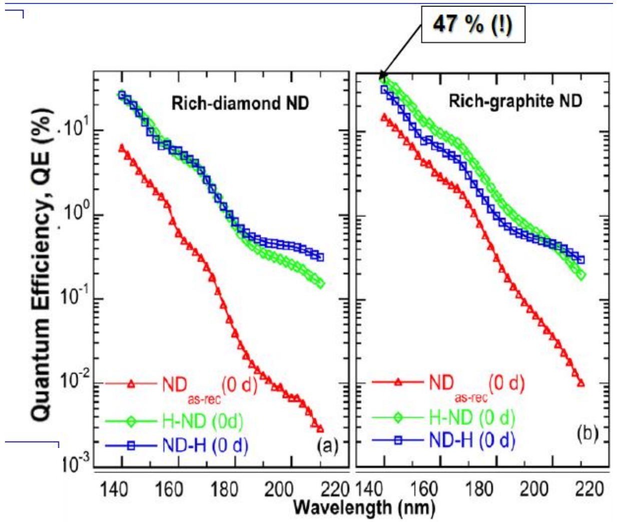
3 tasks on-going (cont.) :

2. **test of novel materials for the THGEM PCB** (for better performance, alternative to FR4):
   - Reminder: previously, Permaglas established for high quality THGEMs
   - Tested material: ARLON 25 FR (an epoxy laminate woven fiberglass reinforced, ceramic filled composites using a non-polar, low loss, thermoset resin), comparing with FR4
     - ✓ Gain, resolution: ok
     - ✓ Time evolution: very slow with ARLON
     - ✓ material memory: reduced gain persistent for months after exposure to X-ray source!
     - ✓ ARLON → NOT adequate for THGEMS

3. **initial studies of the compatibility of an innovative photocathode based on NanoDiamond (ND) particles with the operation in MPGD-based photon detectors**
   - December 2017: meeting between the INFN Trieste and INFN Bari (the group who introduced the novel ND photocathodes)
     - ✓ planning and methodology discussed in detail
     - ✓ production of a few photocathode samples scheduled







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Progress @ INFN Trieste: Plans for the future

- Next future (2018):

    1. MICROMEGAS prototype with miniaturized pad-size
        - ✓ Systematic laboratory studies (MICROMEGAS alone and coupled to 2 two THGEM layers)
        - ✓ Preparation of the test beam studies (scheduled for the end of 2018)
    2. Coupling of innovative photocathode based on NanoDiamond (ND) particles to MPGD photon detectors
        - ✓ comparative measurements of QE in vacuum and in various gas atmospheres
        - ✓ compatibility of ND photocathodes with operation in gases (dust release, if any)
        - ✓ preliminary characterization of a MPGD equipped with the ND photocathode

    - Corresponding MILESTONES:
        - ✓ September 2018: *The completion of the laboratory characterization of the photon detector with miniaturized pad-size.*
        - ✓ September 2018: *The completion of the tests to establish the compatibility of the ND photocathodes with the operation of MPGD-based photon detectors.*

- Further future (> 2018):
    - comparison of THGEM vs GEM photocathodes in order to select the best architecture for the photon detectors of the EIC RICH;
    - further studies in order to enhance the IFB suppression in hybrid MPGDs;
    - operation of hybrid MPGDs in fluorocarbon-rich gas mixtures;
    - *if the compatibility of ND photocathode and MPGD is established,* further studies of MPGD-based photon detectors with ND photocathodes.

eRD6 Publication List: Breakdown per institute

eRD6 Publication List: Breakdown per institute

❖ Brookhaven National Lab

1. B. Azmoun et.al., "*A Study of a Minidrift GEM Tracking Detector*", IEEE Transactions on Nuclear Science, Vol. 63, No. 3 (2016) 1768-1776; https://doi.org/10.1109/TNS.2016.2550503.
2. C.Woody et.al., "*A Prototype TPC/Cherenkov Detector with GEM Readout for Tracking and Particle Identification and its Potential Use at an Electron Ion Collider*"; https://inspirehep.net/record/1409973/files/arXiv:1512.05309.pdf.
3. B. Azmoun et al.; "*Initial studies of a short drift GEM tracking detector*", In: 2014 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC). Nov. 2014; https://doi.org/10.1109/NSSMIC.2014.7431059
4. M. L. Purschke et al. "*Test beam study of a short drift GEM tracking detector*", In: 2013 IEEE Nuclear Science Symposium and Medical Imaging Conference (2013 NSS/MIC). Oct. 2013; https://doi.org/10.1109/NSSMIC.2013.6829463
5. **B. Azmoun, et al., "Design Studies for a TPC Readout Plane Using Zigzag Patterns with Multistage GEM Detectors," submitted for publication in IEEE Transactions on Nuclear Science, Jan. 2018. (Also submitted to arXiv:** http://arxiv.org/abs/1801.03087)

❖ Florida Tech

1. **M. Hohlmann et al. "*Low-mass GEM detector with radial zigzag readout strips for forward tracking at the EIC*", In: 2017 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC 2017) Atlanta, Georgia, USA, October 21-28, 2017;** http://inspirehep.net/record/1636290/files/arXiv:1711.05333.pdf
2. **A. Zhang et al. "*A GEM readout with radial zigzag strips and linear charge-sharing response*"; In: Nucl. Instr. Meth. A, article in press (2017). arXiv:** https://arxiv.org/abs/1708.07931v1
3. A. Zhang and M. Hohlmann, "*Accuracy of the geometric-mean method for determining spatial resolutions of tracking detectors in the presence of multiple Coulomb scattering*," JINST 11 P06012 (2016), June 21, 2016; https://doi.org/10.1088/1748-0221/11/06/P06012
4. A. Zhang et al. "*R&D on GEM detectors for forward tracking at a future Electron-Ion Collider*", In: Proceedings, 2015 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC 2015): San Diego, California, United States. 2016, p. 7581965; https://doi.org/10.1109/NSSMIC.2015.7581965
5. A. Zhang, et al., "*Performance of a large-area GEM Detector read out with wide radial zigzag strips*," Nucl. Inst. Meth. A 811 (2016) 30-41; https://doi.org/10.1016/j.nima.2015.11.157

eRD6 Publication List: Breakdown per institute

❖ INFN Trieste

N/A; Just Started

❖ Stony Brook University:

1. M. Blatnik et al., "*Performance of a Quintuple-GEM Based RICH Detector Prototype*", In: IEEE Trans. Nucl. Sci. 62.6 (2015), https://doi.org/10.1109/TNS.2015.2487999

❖ Univ. of Virginia

1. K. Gnanvo et al., "*Performance in Test Beam of a Large-area and Light-weight GEM detector with 2D Stereo-Angle (U-V) Strip Readout*", Nucl. Inst. and Meth. A808 (2016); https://doi.org/10.1016/j.nima.2015.11.071
2. K. Gnanvo, et al. "*Large Size GEM for Super Bigbite Spectrometer (SBS) Polarimeter for Hall A 12 GeV program at JLab*", Nucl. Inst. and Meth. A782, 77-86 (2015); https://doi.org/10.1016/j.nima.2015.02.017

❖ Yale University

1. S. Aiola et al., "Combination of two Gas Electron Multipliers and a Micromegas as gain elements for a time projection chamber", Nucl. Inst. and Meth. A834 (2016); https://doi.org/10.1016/j.nima.2016.08.007

INFN Trieste addressing specific issues from the January 2017 committee report

Response from INFN Trieste: In the report about INFN activity

Summarized in short form

COMMENTS

- **THGEM is an old detector concept (15-20 years)**
- **Coupling THGEMs and Nanodiamond (ND) photocathode:**
  - **Working down to 140 nm critical because of**
    - ✓ **Chromatic dispersion**
    - ✓ **Media transparency**
    - ✓ **Issues of THGEM outgassing**
- **Why not using MCP coupled to MM (NIMA 535 (2004) 334, NIMA 553 (2005) 76) ?**

RECOMMENDATION

- **new photocathode material is very interesting**
  - **important to understand more thoroughly how the operation at very short wavelengths will actually occur**
  - **Thick GEMs will complicate that picture because of G-10 outgassing water**

UNIVERSITY of VIRGINIA

Response from INFN Trieste: THE CONTEXT OF THE INFN R&D

Low p (< 5-6 GeV/c, higher ?)

- **Options**
  - Proximity focusing RICHes using
    - ✓ C_6F_{14} (or analogous)
    - ✓ aerogel
  - DIRC & derived detectors
    - ✓ FDIRC, TOP, TORCH
  - Alternative approaches
    - ✓ New TOF perspectives
    - ✓ Improved dE/dx by cluster counting in gas

Imaging Cherenkov

t resolution ~O(10ps)

- Progress related to numerous **new projects**:
  - Belle-II barrel
  - Belle-II forward
  - CLAS12
  - GlueX
  - Panda barrel
  - Panda end-caps
  - Panda forward
  - LHCb-Torch

List from RICH2016

High p (> 1-4 GeV/c)

Our focus

- **Option**
  - Focusing RICHes with extended gaseous radiator
- Presently only **3 running high-p RICHes:**
  - LHCb (2-counter system)
  - NA62 (non h-PID!)
  - COMPASS, upgraded : novel MPGD-based PDs
- **Further future projects:**
  - Only EIC

h physics needs

- Can the radiator be "thinner" to avoid gigantic sizes: (advantages for colliders, also for fixed target)?
  namely more detected photons per unit radiator length
- proposed so far
  - P > 1 atm, proposal for ALICE HMPID upgrade, then abandoned
  - Exploit the VUV region with a windowless RICH, testbeam @ Fermilab
  - Use vacuum-based (visible light) photon detectors

gaseous PDs

IEEE NS 62 (2015) 3256

Response from INFN Trieste: THE CONTEXT OF THE INFN R&D

Low p (< 5-6 GeV/c, higher ?)

- **Options**
  - Proximity focusing RICHes using
    - ✓ C_6F_{14} (or analogous)
    - ✓ aerogel
  - DIRC & derived detec...
    - ✓ FDIRC...

Imaging Cherenkov

...da barrel
- Panda end-caps
- Panda forward
- LHCb-Torch

List from RICH2016

World-wide activity ongoing for h PID at low momenta (interest of a wide scientific community) :

a suitable and convincing approach for experiments at EIC can be found within this context

High p (> 1-4 GeV/c)

- **Opti...**

Very limited recent activity for h PID at high momenta (in the next years only R&D for EIC foreseen): **our focus is here**

Extra difficulty: compress the radiator length to match the requirements of a collider setup

No consistent detector concept existing yet; most likely upgraded gaseous photon detectors have to be used (central brick for a RICH) **: this is the goal of the present stage of our R&D** (later: move to a complete detector concept)

...(2015) 3256

...(visible light) photon detectors

Response from INFN Trieste: About THGEMs

- **YES, the concept is old**

  (reminder: THGEM also called LEM in literature)

- **So far used in a single experiment: novel photon detectors of COMPASS RICH-1**
  - **it took years to understand them and reach production technique maturity (R&D for COMPASS: 7 years)**

- **THGEM outgassing**
  - **important ingredient: bake them to complete epoxy curing (not the case for standard PCB production)**
  - **Form direct experience:**

    Vacuum level while pumping

    in order to prepare

    for CsI coating

THGEM introduced in // by different groups:

L. Periale et al., NIM A478 (2002) 377

P. Jeanneret, PhD thesis, Neuchatel U., 2001

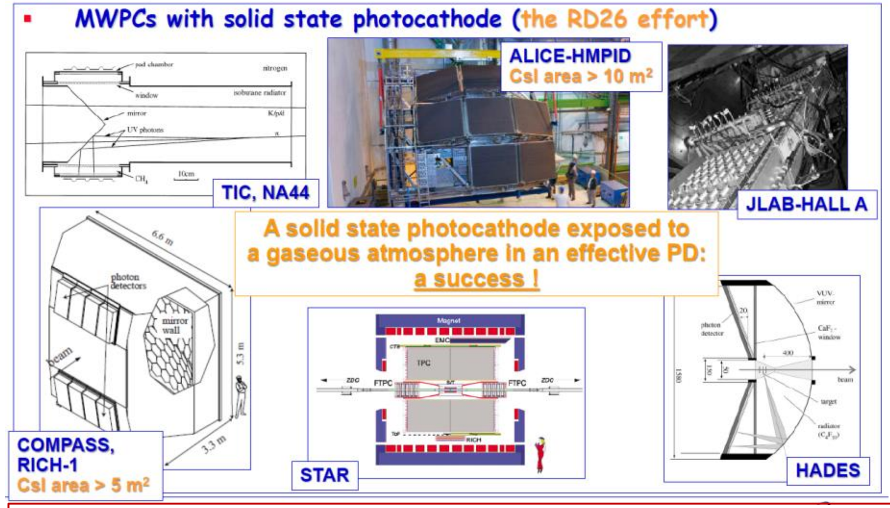
P.S. Barbeau et al., IEEE NS50 (2003) 1285

R. Chechik et al., NIMA 535 (2004) 303

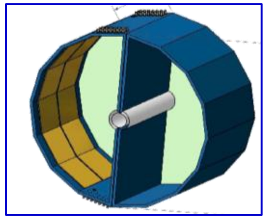
Response from INFN Trieste: ABOUT OPERATION IN THE FAR UV DOMAIN

FACTS

CsI gasous sensors used in several Cherenkov detectors

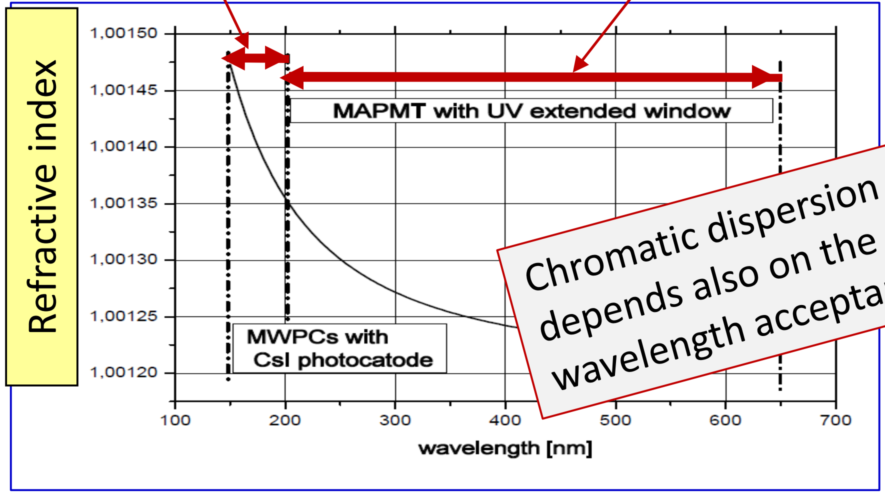


PHENIX HBD
CsI + GEMs



(n-1) r.m.s *(assuming Frank and Tamm):*

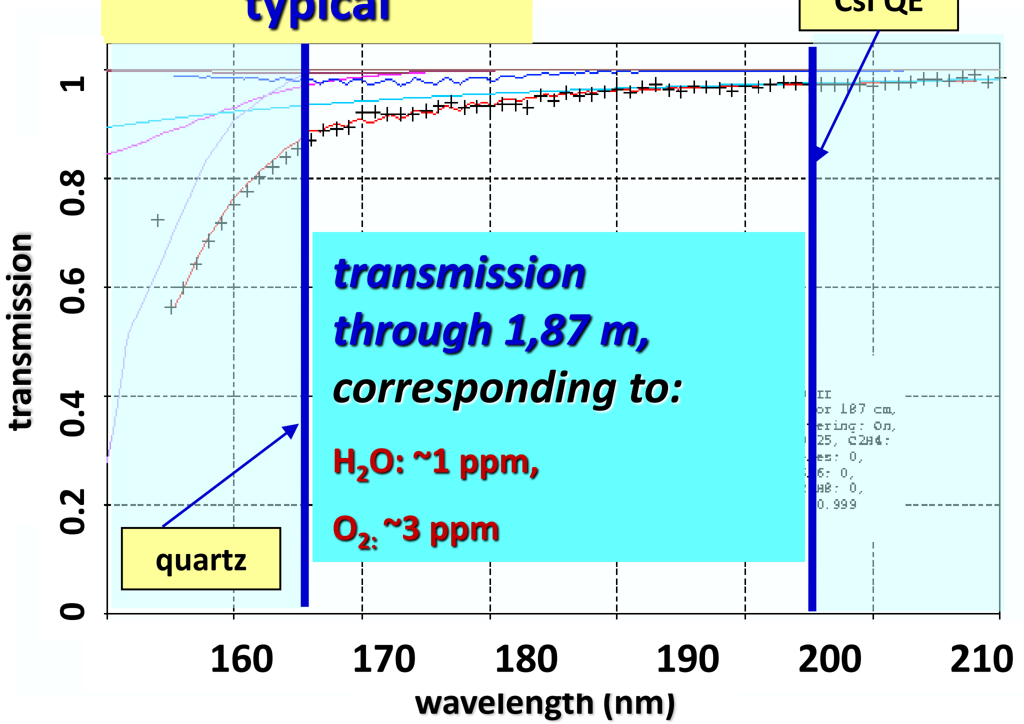
30×10^{-6} < 46×10^{-6}



Chromatic dispersion depends also on the wavelength acceptance range

COMPASS RICH-1, gas transparency

- -gas cleaning by on-line filters,
- -separate functions:
  - -Cu catalyst, ~ 40⁰C for O_2
  - -5A molecular sieve, ~ 10⁰C for H_2O



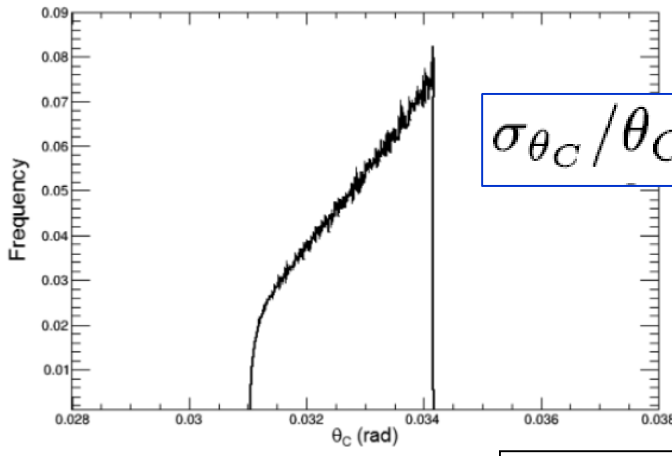
transmission through 1,87 m, corresponding to:

H_2O: ~1 ppm,

O_2: ~3 ppm

Response from INFN Trieste: ABOUT OPERATION IN THE FAR UV DOMAIN

- **A RICH prototype has explored the very far UV domain**
  - in a windowless RICH using CF_4
  - Using quintuple GEMs and CsI
  - by using a thin-film mirror (25 nm MgF_2), reflecting in a limited range around 120 nm

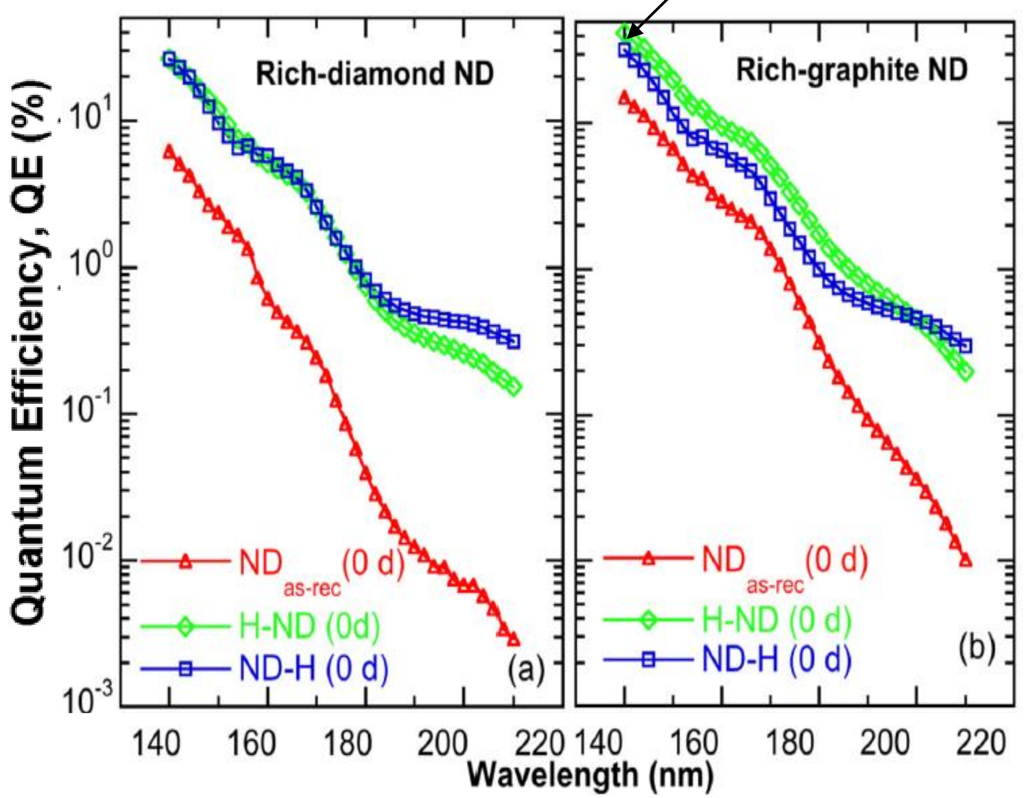


$$\sigma_{\theta_C}/\theta_C \sim 2.5\%$$

IEEE NS 62 (2015) 3256

- **QE is similar in ND and CsI**
- **ND is expected to be by far more robust**

47 % (!)



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Response from INFN Trieste: MCP coupled to MM

- **Most likely interesting, nevertheless a completely different approach that would require restarting from scratch …**

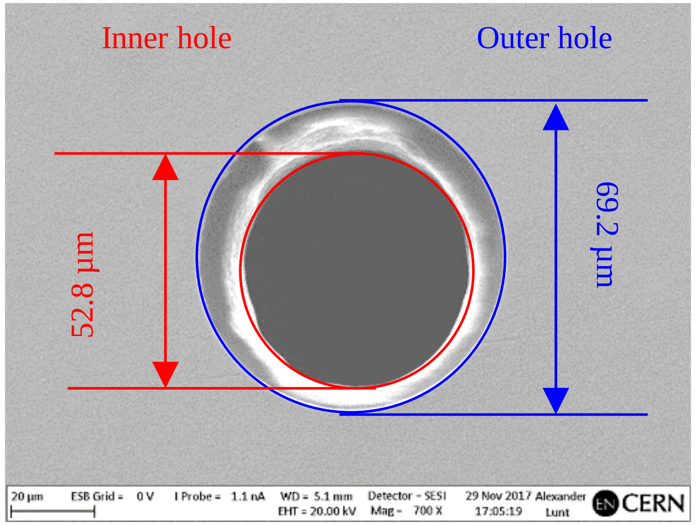
- **At the moment, not considered**

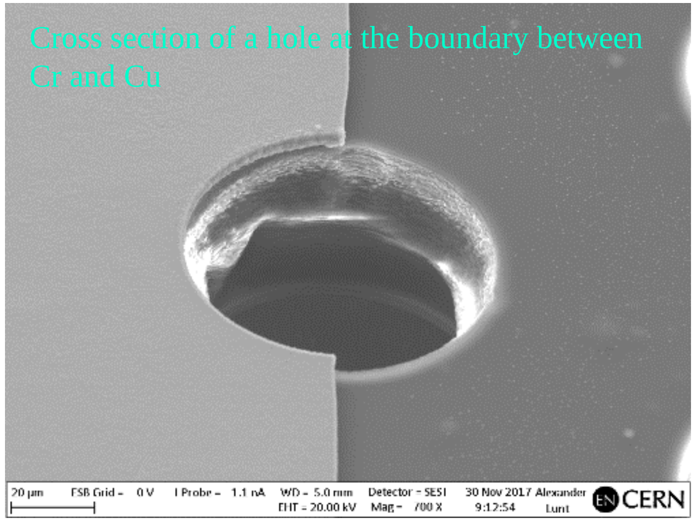
Backup

Progress @ UVa: Optical & SEM Inspection of Chromium GEMs

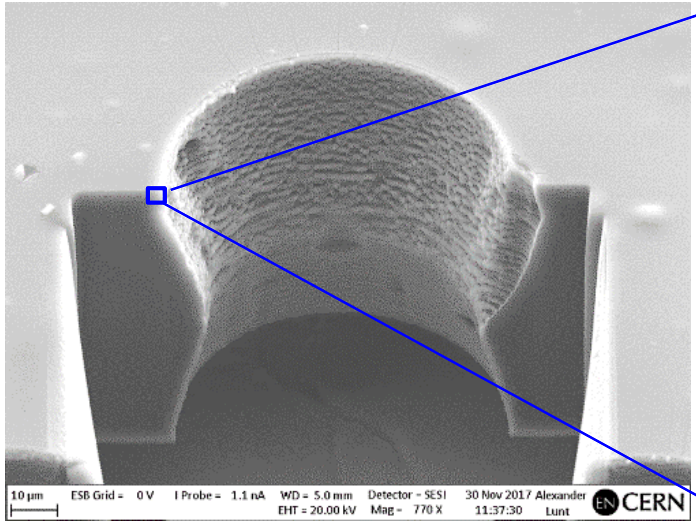
- **SEM and FIB analysis of Cr-GEMs @ CERN (11/2017) to:**
  - investigate Cr and Kapton etching?
  - Measure the thickness of the Cr layer
- **Samples from 4 GEM foils sent to CERN:**
  - Cr-GEM1: damaged foil as 3rd GEM in proto I ⇨ high rate.
  - Cr-GEM2: 3rd GEM in proto II ⇨ long exposure
  - Cr-GEM3: 2nd GEM in 2 protos ⇨ high rate & long exposure
  - std-GEM: standard GEM foil with 5 µm electrode

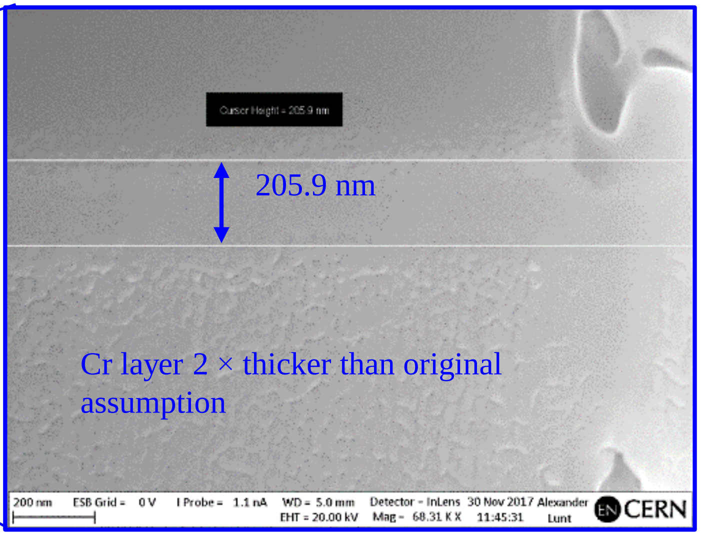
Good foil (Cr-GEM3)





Cross section of Cr-GEM hole and thickness of Cr layer





eRD6 Consortium: What was achieved the past period

❖ Brookhaven National Laboratory (BNL)

- Optimization of the zigzag pad readout pattern parameters, fabrication of PCB with this readout pattern and measurement of the position resolution
- Refining the analysis of the beam test results from TPC-C prototype, ***(in collaboration with SBU)***
- Draft paper for submission to IEEE TNS
- Initial results from TPC gas studies

❖ Florida Institute Of Technology (FIT)

- Inspection of the zigzag structure under a microscope of large readout board and HV test of the common GEM foil
- In-home production of the outer carbon fiber frames completed and mechanically tested and validated
- Manuscript on the performance of improved zigzag structures in preparation for NIM A

❖ INFN Trieste

- Test of novel materials for the THGEM PCB
- Development of resistive MM by discrete elements with miniaturized pad size

❖ Stony Brook University (SBU)

- Procurement of all needed equipment for the upgrade of existing CsI evaporator
- Preparation of the evaporation equipment to be installed into the evaporator

❖ University Of Virginia (UVa)

- Aging test of Cr-GEM with x-ray and validation of double zebra connection scheme on small GEM prototype
- Finalize large U-V strips readout and zebra connection and support frame design.
- Production of the board and the zebra connection pieces is ongoing at CERN.

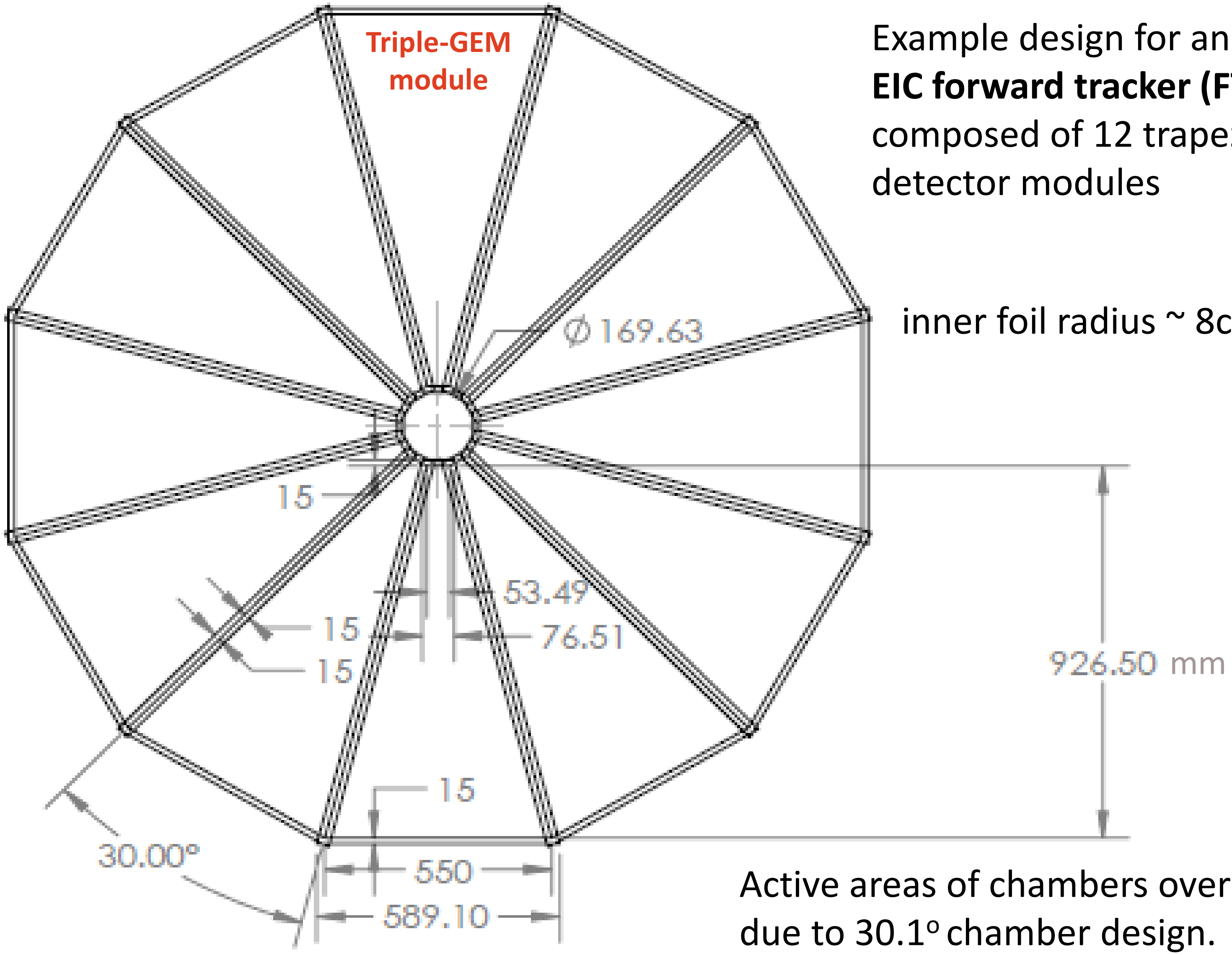
❖ Yale University

- Hybrid Gain Structure for TPC read-out – 2 GEMs plus Micromegas (2-GEMs + MMG).
- Multi-element stacked gated grid

EIC FT Geometry Option

Desired Module Properties:

- Easy assembly
- Mechanical stability
- Low multiple scattering
- High spatial resolution
- Reasonable cost

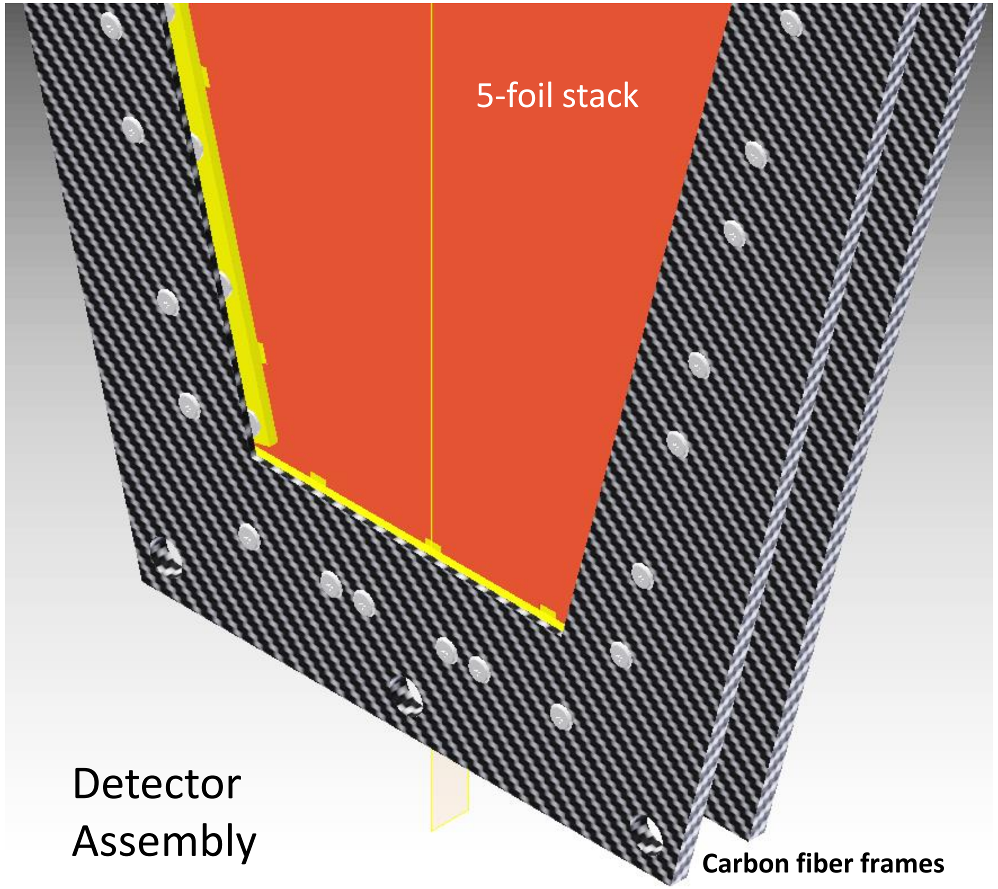


Example design for an **EIC forward tracker (FT) disk** composed of 12 trapezoidal GEM detector modules

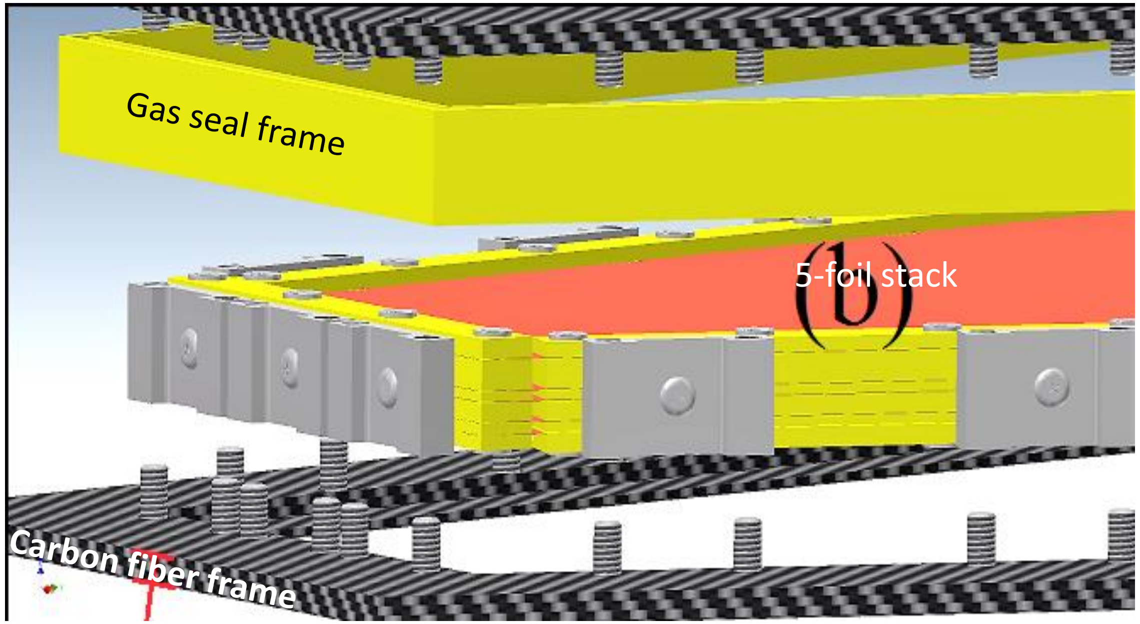
inner foil radius ~ 8cm

Active areas of chambers overlap due to 30.1° chamber design.

Carbon Fiber Frames & Assembly



Exploded assembly view



- Mechanical support structures are **outer frames with thin windows** (e.g. aluminized mylar foil or kapton, not shown here) instead of solid PCBs to reduce radiation length in the active area
- **Frames are made from carbon fiber composites** that have high strength to take up the tension from the stretched foils in the stack

Progress @ INFT Trieste: Complementary Information

- Personnel (globally equivalent to 3 FTE):
  - From INFN Trieste:
    - ✓ M. Baruzzo (Trieste University and INFN, master student)
    - ✓ C. Chatterjee (Trieste University and INFN, PhD student)
    - ✓ S. Dalla Torre (INFN, Staff)
    - ✓ S. Dasgupta (INFN, postdoc)
    - ✓ S. Levorato (INFN, Staff)
    - ✓ F. Tessarotto (INFN, Staff)
    - ✓ Y. Zhao (INFN, postdoc)
    - ✓ *technical personnel from INFN-Trieste foreseen according to needs*
  - From INFN BARI:
    - ✓ Grazia Cicala (Bari University staff and INFN)
    - ✓ Antonio Valentini (Bari University and INFN, professor)

- External Funding
  - 2018 INFN support for this activity: 12 k €
    - ✓ *Reminder* - 2017 INFN support : 13 k €